Characterization of Framing Factors for Low-Rise Residential Building Envelopes in California

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Legal Notice

Acknowledgements

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace. The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial / Agricultural / Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

What follows is the final report for the "Characterization of Framing Factors for Low-Rise Residential Building Envelopes in California" project, Contract Number: #400-00-02, conducted by Enermodal Engineering, Inc., 1554 Emerson Street, Denver, Colorado, 80218. This project contributes to the Buildings End-Use Energy Efficiency program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/pier/reports.html or contact the Commission's Publications Unit at 916-654-5200.

Executive Summary

The State of California has an energy code (Title 24) that requires building envelope assemblies to meet or exceed a specific R-value. Designers typically show compliance by adding up the thermal resistances of each layer in the assembly (i.e. parallel-path method). When there is more than one path through the assembly, for example through the insulation and through the wood framing in the case of a wood-framed wall, the thermal resistance through each path is calculated and area weighted.

Title 24 provides recommended values for the amount of area represented by framing. Unfortunately the source of this data is not well substantiated. The accuracy and suitability of framing data from other sources, such as the ASHRAE Handbook of Fundamentals is equally unsubstantiated. To address this problem, ASHRAE recently contracted Enermodal Engineering Ltd. (EEL) to conduct a survey of current framing practices in the four major census regions: North East, Mid-West, West and South [Enermodal, 2001]. The survey included detached, attached and multi-unit dwellings from each census region, for a total of 120 dwellings. Dwellings in high seismic or high wind regions were excluded from the survey. As a result, the State of California was not included in the ASHRAE survey. This study extends the methodology used in the ASHRAE project to the State of California.

Objectives

The overall goal of the project is to improve the accuracy of calculating overall envelope heat loss/gain. The objectives of this work are to:

- Develop a statistically representative set of framing factors (table next page) for low-rise dwellings in the State of California
- Identify differences in framing factors according to seismic region
- Quantify the distribution of framing within dwellings (e.g., walls, windows, ceilings)
- Present the information in a form that can be used by the California Energy Commission in its energy code

Sixty dwellings were audited during construction to assess the amount of framing. The dwellings were distributed in two seismic zones of California and three dwelling types (single detached, attached and multi-family) so as to obtain statistically significant samples for each dwelling type and zone. The size and style of dwelling within each group were selected to represent the range in that region. The study was restricted to wood-framed dwellings.

The amount of framing is expressed in two ways: gross and net. The gross values are the amount of framing in an envelope component (wall, floor, or ceiling) divided by the gross component area (including the area of any openings). The net values are the amount of framing in the component divided by the framed area (excluding the area of any openings). The framing factors based on the net area should be used whenever the net area is known.

Outcomes

A statistically representative set of framing factors was developed for low-rise dwellings in the State of California

Differences between the framing factors for seismic regions three and four were examined and found to be insignificant

The distribution of the framing has been quantified and relationships between framing factors and various dwelling characteristics are discussed

The framing factors were presented in tabular format that can be used by the California Energy Commission in its energy code

Conclusions

The following conclusions can be drawn about framing in dwellings.

— Approximately 18 percent of the gross wall area is taken up by openings for windows and doors. The amount of openings in floors and ceilings is negligible (less than one percent of the gross area)

The framing factors for attached, detached and multi-family dwellings are very similar and can be represented by a single set of values

— There is very little difference in the framing factors for seismic zones three and four. A single set of values can represent both regions

The framing factors found in the California and the ASHRAE (national) study are summarized below. The results are very similar and as such, it appears that little additional framing is used in California to meet the seismic requirements.

Recommended Table of Framing Factors (all values in %)

Component	ASHRAE (National) Results	California Results
Window Area to Gross Wall Area	**12**	**12**
Door Area to Gross Wall Area	**5**	**7**
Rim Joist Area to Gross Wall Area	**4**	**Not Available – See Note**
Framing Factors	Net	Net
Ceiling	**7**	**7**
Wall	**25**	**27**
Floor	**12**	**Not Available – See Note**
Overall	**16**	**15**

Note: Since the vast majority of dwellings in the State of California are constructed on slab-on-grade foundations, there is not sufficient framed floor data to calculate framing factors related to the floor. Rim Joist Area is included in the Gross and Net Wall Areas. See also Framing Factor Definitions in Section 3.6 of this report.

Benefits to the State of California

This study has examined the amount of framing in residential building envelopes. This information improves the ability of engineering and design professionals to determine the effects of insulation strategies on building energy use.

By properly assessing the energy performance of building envelopes, the market will be encouraged to use the insulation strategies that provide optimal benefits. The net effect will be to reduce energy use in new California homes

Recommendations

Observations made during the site surveys suggest that architectural complexity and builder practices have an impact on the amount of framing used in the construction of low-rise dwellings. As these were not the focus areas in this study, the following are recommended:

- Further research to identify those architectural features that require the most framing and create the largest thermal bridges.
- Efficient framing methods (e.g. stack framing) should be further developed and a formal training program should be established to encourage builders to implement these practices.

Abstract

This study develops the understanding of the interaction of heat flow through the building envelope with differing framing practices. A field survey of 60 low-rise dwellings was conducted to develop a statistically representative set of framing factors for the State of California. The survey employed the methodology used in a similar ASHRAE sponsored survey of current framing practices in the four major census regions: North East, Mid-West, West and South. Detached, attached and multi-unit dwelling types were considered in both surveys.

Some of the key topics discussed in this study are:

- Framing factors for dwellings in non-seismic areas (i.e. from the ASHRAE study) are compared to those of seismic zones three and four in the State of California.
- The distribution of the framing is quantified and relationships between framing factors and various dwelling characteristics are discussed, and
- The framing factors are presented in a tabular format that can be easily adopted by practicing engineering and design professionals.

1.0 Introduction

Residential building energy codes (such as Title 24, ASHRAE 90.2, and the Model Energy Code) require building assemblies to meet or exceed a specific R-value. The requirements are usually a function of assembly type (e.g., wall, ceiling), climatic zone and in some cases fuel type. Designers typically show compliance with these requirements by performing a set of calculations that add up the thermal resistances of each layer in the assembly (i.e. parallel-path method). When there is more than one path through the assembly, for example through the insulation and through the wood framing in the case of a wood-framed wall, the thermal resistance through each path is calculated and area weighted.

Performing the area weighting requires knowledge of the relative amounts of each path in the assembly. For wood-frame buildings, this would seem to be a simple task since the studs are installed at equal spacings (e.g., 16 or 24" on center). The reality is that architectural features complicate residential construction and additional framing must be added in corners, around windows and doors, between floors and for blocking and bracing.

Having more accurate and representative framing percentages offers four benefits. First, more accurate data can have a significant effect on total-assembly R-value because heat transfer is much higher through the studs than through the insulation. For example, an eight-point increase in percentage framing (from 11 to 19 percent) reduces total-wall R-value by 12 percent. Second, using a more representative framing percentage may alter the relative cost-effectiveness between building assemblies (e.g., 2X6 vs. 2X4 with insulated sheathing vs. concrete block). Third, building assemblies that currently qualify in energy codes may no longer qualify if more representative framing factors are used (and vice versa). Fourth, the energy benefit of more efficient wood framing techniques (e.g., 2-stud corners) could be calculated (and accounted for in codes).

In September 1999, the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) contracted Enermodal Engineering Ltd. (EEL) to conduct a survey of current framing practices in the four major census regions: North East, Mid-West, West and South [Enermodal, 2001]. The survey included detached, attached and multi-unit dwellings from each census region, for a total of 120 dwellings. Dwellings in high seismic or high wind regions were excluded from the survey. As a result, the State of California was not included in the ASHRAE survey.

The California Energy Commission contracted Enermodal to extend the ASHRAE survey program to California. The overall goal of the project is to improve the accuracy of calculating overall envelope heat loss/gain.

1.1. Objectives

The objectives of this work are to:

- Develop a statistically representative set of framing factors for low-rise dwellings in the State of California,
- Identify differences in framing factors according to seismic region,
- Quantify the distribution of framing within dwellings (e.g., walls, windows, ceilings), and
- Present the information in a form that can be used by the California Energy Commission in its energy code.

1.2. Approach

Sixty dwellings were audited during construction to assess the amount of framing. The dwellings were distributed in two seismic zones (Zone Three and Zone Four) for three dwelling types (single detached, attached and multi-family) so as to obtain a statistically significant sample for each dwelling type and zone. The size and style of dwelling within each group were selected to represent the range in that zone. The data was analyzed in a database program to determine the amount and type of framing in the same manner as that used in the ASHRAE research project.

For the purpose of this research report, the following terms shall have the meanings indicated:

Attached Single-Family Dwelling: A single-family dwelling unit constructed in a row of attached units separated by property lines and with open space on at least two sides.

Detached Single-Family Dwelling: Any building which contains one dwelling, used, intended or designed to be built, and is occupied for living purposes.

Dwelling: A single unit providing complete independent living facilities for one or more persons, which includes permanent provisions for living, sleeping, eating, cooking, and sanitation [International Code Council-2000].

Multi-family Low-Rise Dwellings: A group of single-family units contained in a two- or three-story building where the occupants are non-transient in nature (e.g. apartment dwelling).

Steel-framed dwellings were not included so as to minimize the number of variables and to focus resources on the major framing type used in California.

2.0 Background Information

2.1. Published Values of Framing Factors

Several sources have published data on the percentage framing in wood frame dwellings. Table 1 lists the framing values which are used in the State of California Title 24 Energy Code calculation methods (adopted in 1998 and unchanged in 2001). Table 2 lists "typical" values of percent framing from previous versions of the ASHRAE Handbook of Fundamentals.
Table 3 lists the values given in the Canadian Model National Energy Code for Houses. These sources represent a large variation in the amount of framing: from 15 percent to 25 percent for 16" stud spacing and from 9 percent to 22 percent for 24" stud spacing.

Table 1: Framing Factors from California Title 24

Component	16" Stud Spacing	24" Stud Spacing
Walls	**15%**	**12%**
Floors and Ceilings	**10%**	**7%**
***Overall*[1]**	***12.5%***	***9.5%***

[1] – Overall values are estimated assuming equal area of floor/ceiling and above-grade walls

Table 2: Framing Factors from the ASHRAE Handbook of Fundamentals

Component	1985 & 89 ASHRAE Handbook 16" Studs	1985 & 89 ASHRAE Handbook 24" Studs	1993 & 97 ASHRAE Handbook 16" Studs	1993 & 97 ASHRAE Handbook 24" Studs
Studs & Sills	**N/A**	**N/A**	**21%**	**18%**
Headers	**N/A**	**N/A**	**4%**	**4%**
Total	**15%**	**12%**	**25%**	**22%**

Table 3: Framing Factors from the Canadian Model National Energy Code for Dwellings

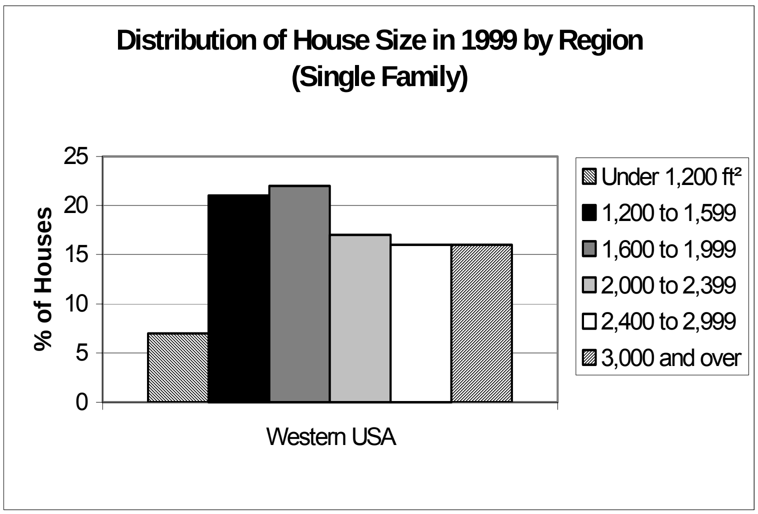
Component	16” Stud Spacing	24” Stud Spacing
Roofs, Ceilings, Floors	10%	7%
Above-Grade Walls	19%	11%
Below-Grade Walls	17%	10%
Overall[1]	15%	9%

[1] – Overall values are estimated assuming equal area of floor/ceiling and above-grade walls

The value of this data is limited in three ways. First, the source and representativeness of this data is not known. It does not appear to be based on a statistically valid sampling procedure. Second, given the wide range in dwelling types (e.g., detached, attached, multi-unit), regional construction practices and dwelling designs, it is likely that a single value is not representative of all cases. Third, the ASHRAE data does not provide values for ceilings and floors. It is important to know where the framing is to evaluate its impact on the assembly R-value. Framing in attics may have a lower effect on assembly R-value than for walls because ceiling joists are often covered by blown-in insulation.

2.2. Characteristics of Single-family Survey Sites

Single-family survey sites include both detached and attached dwellings (e.g. town houses, link homes (connected by party wall on one side and garage on other side) and semis (connected by party wall on one side only)). The majority of the single-family dwellings are stick-built (i.e. dwellings built on site using small structural members). Dwellings built using modular framing systems (i.e. factory-built) and other methods only account for two percent of the single-family dwellings constructed in Western USA in 1999 (US Census Bureau). The single-family dwellings constructed in 1999 are evenly divided between one story and two or more stories in height. Split-level homes represent only one percent of construction in Western USA. The majority are constructed on slab-on-grade floors. This study only includes stick-built dwellings. Figure 1 illustrates the distribution of single-family dwellings by dwelling size and geographic region. The ASHRAE framing survey used <2500 ft² (gross floor area) and >2500 ft² as the two categories to classify smaller and large dwellings. These categories are also used in this survey.



Adapted form US Census Bureau data

Figure 1: Distribution of Single-family Dwelling Sizes in 1999

The single-family survey sites in each zone were selected to achieve as close as possible the following criteria:

Framing Method: 100 percent stick built

Number of Stories: 50 percent one story, 50 percent two stories

Foundation Type: 90 percent slab on grade, 10 percent basement or crawlspace

Floor Area: 60 percent under 2500 ft², 40 percent over 2500 ft²

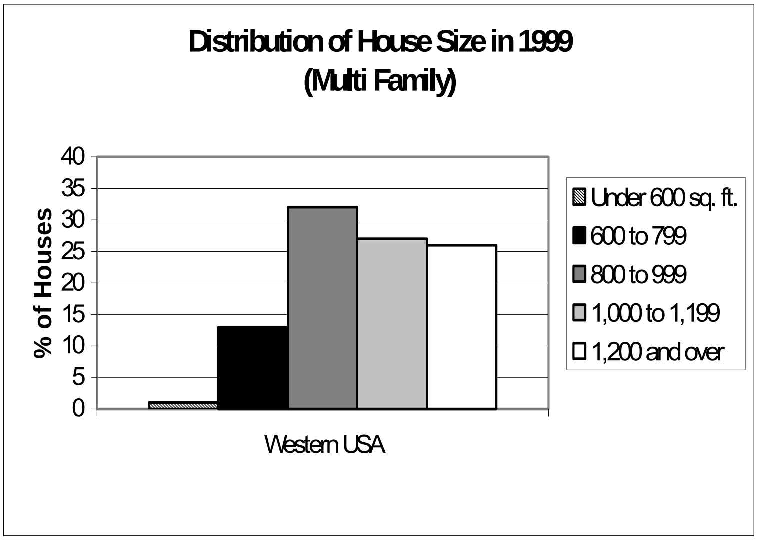
No more than three dwellings can be used from any single contractor

No dwelling plan can be used more than once

2.3. Characteristics of Multi-family Survey Sites

Multi-family buildings are made up of units that only have access from one side. They can contain multi-story units, one-story units, split-level units or a combination thereof. For the ASHRAE framing survey, Multi-unit buildings must contain a minimum of 8 units and must not be more than 3 stories in height. These rules were also applied to this survey.

Figure 2 illustrates the distribution of size of units in multi-family dwellings. The ASHRAE framing survey used <1000 ft^2 (gross floor area) and >1000 ft^2 as the two categories to classify smaller and large units. These categories are also used for this survey.



Adapted form US Census Bureau data

Figure 2: Distribution of Multi-Family Dwelling Sizes in 1999

The multi-family survey sites in each zone will be selected to achieve as close as possible the following criteria:

Framing Method: 100 percent stick built

Minimum Number of Units: 8

Maximum Number of Stories: 3

Foundation Type: 90 percent slab on grade, 10 percent basement or crawlspace

Floor Area: 40 percent under 1000 ft^2, 60 percent over 1000 ft^2

No more than three buildings can be used from any single contractor

No building plan can be used more than once

3.0 Methodology for Determining Framing Factors

3.1. Overview

The method for determining framing factors consists of five steps as follows.

Step 1 - Locate Suitable Dwellings: The dwelling data must cover all regions of California and be representative of the type of dwelling built.

Step 2 – Audit Dwellings: For each selected dwelling, the auditors collected information on the amount of framing used in the ceiling, walls and floor. The audits were performed when the dwellings were framed but before insulation or drywall was added.

Step 3 – Enter Data into Database: An ACCESS database program was developed to assist the auditors in the collection and storage of the dwelling data

Step 4 – Analyze Dwelling Data: The project manager reviewed all dwelling data for consistency and suitability. The data was analyzed using the database program and conclusions drawn about the amount and type of framing.
Step 5 – Compare to ASHRAE Data: The final step was to determine how the California data compares to recently collected data in the ASHRAE project and account for any differences.

3.2. Geographic Distribution of Data

Two approaches were considered for determining the appropriate geographical distribution of the survey sites. In the first approach, the survey sites would be evenly distributed throughout the different regions that make up the study area. For example, the survey would include ten detached, ten attached and ten multi-family dwellings in each of the two seismic zones that cover California (30 dwellings in Zone 3 and 30 dwellings in Zone 4 = 60 dwellings). A similar approach was used in the ASHRAE framing survey (40 dwellings in each of Northeast, Mid West, West and South census regions). However, our experience from that project suggests that this may not be the best way to distribute the survey sites since it ignores the regional distribution of new construction. As an alternate approach, the geographic distribution of the survey sites would be set up to reflect the amount and type of construction occurring in different regions. If there are more detached dwellings constructed in one region than another, then more detached dwellings would be surveyed in that region. This was the approach taken to determining the geographic distribution of the survey sites in the State of California. Two parameters were considered: definition of seismic zones and census statistics of house starts.

The ICBO - Uniform Building Code (adopted in 1997) (UBC) is used as the basis for all residential construction in the State of California. The UBC defines certain seismic zones for the design of residential buildings to resist earthquake loads. The map in Figure 3 indicates the UBC seismic zones in the State of California. This map also shows the location of the cities included in the California new construction statistics. The size of the city marker suggests the relative amount of new construction taking place in that city.

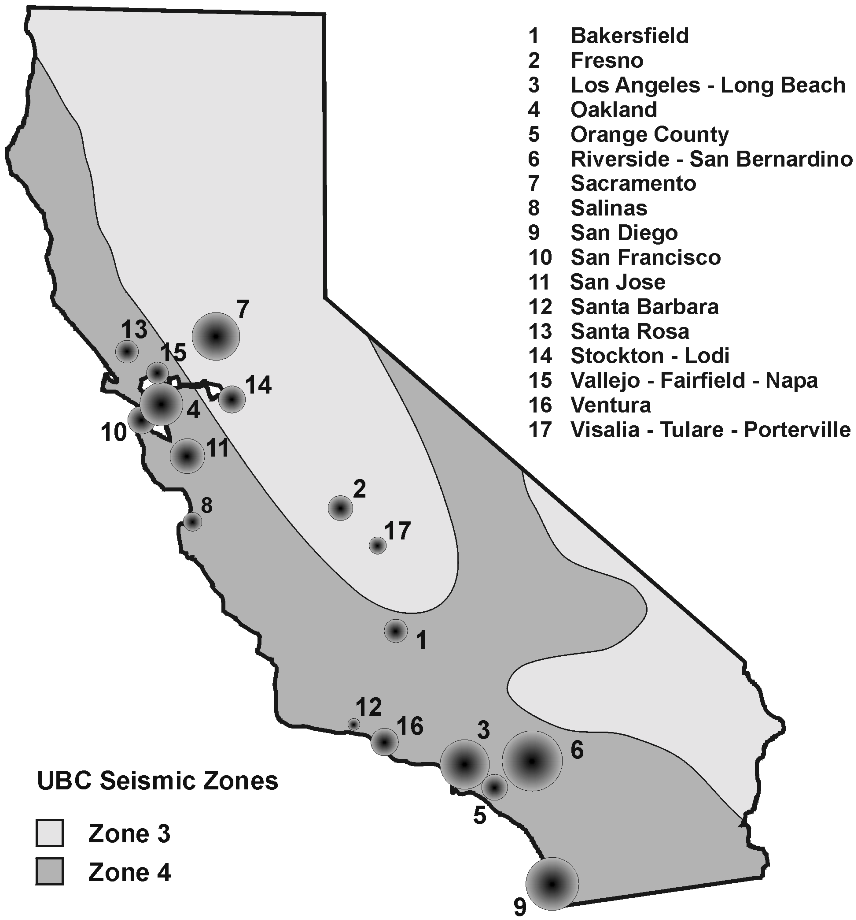


Figure 3: Map of UBC seismic zones and new construction in California

In California, the majority of the cities and over 80 percent of the 1999 new dwelling starts fall into UBC seismic Zone 4 (US Census Bureau data). Using an even distribution of survey sites, only 50 percent of the sites would be in Zone 4. Furthermore, the even distribution places too much emphasis on very small segments of the market. Multi-family dwelling construction in seismic Zone 3 accounts for only three percent of the new Dwelling starts in the State of California today (US Census Bureau data). Using an even distribution, almost 17 percent of the sites would be multi-family buildings from Zone 3.
Table 4 lists the distribution of survey sites used for this study:

Table 4: Distribution of Survey Sites

Dwelling Type	**Seismic Zone 3**	**Seismic Zone 4**	***Total***
Detached	11	19	***30***
Attached	2	16	***18***
Multi-unit	4	8	***12***
Total	***17***	***43***	***60***

This distribution of the survey sites reflects the distribution of 1999 new Dwelling starts (US Census Bureau data) with respect to seismic zone and dwelling type while ensuring that sample sizes are not too small to identify trends. This data provides reasonably accurate framing percentages for each dwelling type in California and identifies trends related to construction practices in the two seismic zones.

3.3. Representative Data

To ensure framing factors are meaningful, the dwellings surveyed are representative of new dwellings constructed in the State of California. Sixty sites are included in this study. These are distributed to reflect U. S. Census Bureau statistics, the seismic design requirements of the Uniform Building Code and conversations with housing experts from the State of California. The U. S. Census Bureau reported approximately 138,000 new dwelling starts (single and multi-family) in California in 1999. This represents an 11 percent increase over 1998 and a 26 percent increase over 1997. Figure 4 illustrates the distribution of single and multi-family dwellings constructed in 1999 by city.

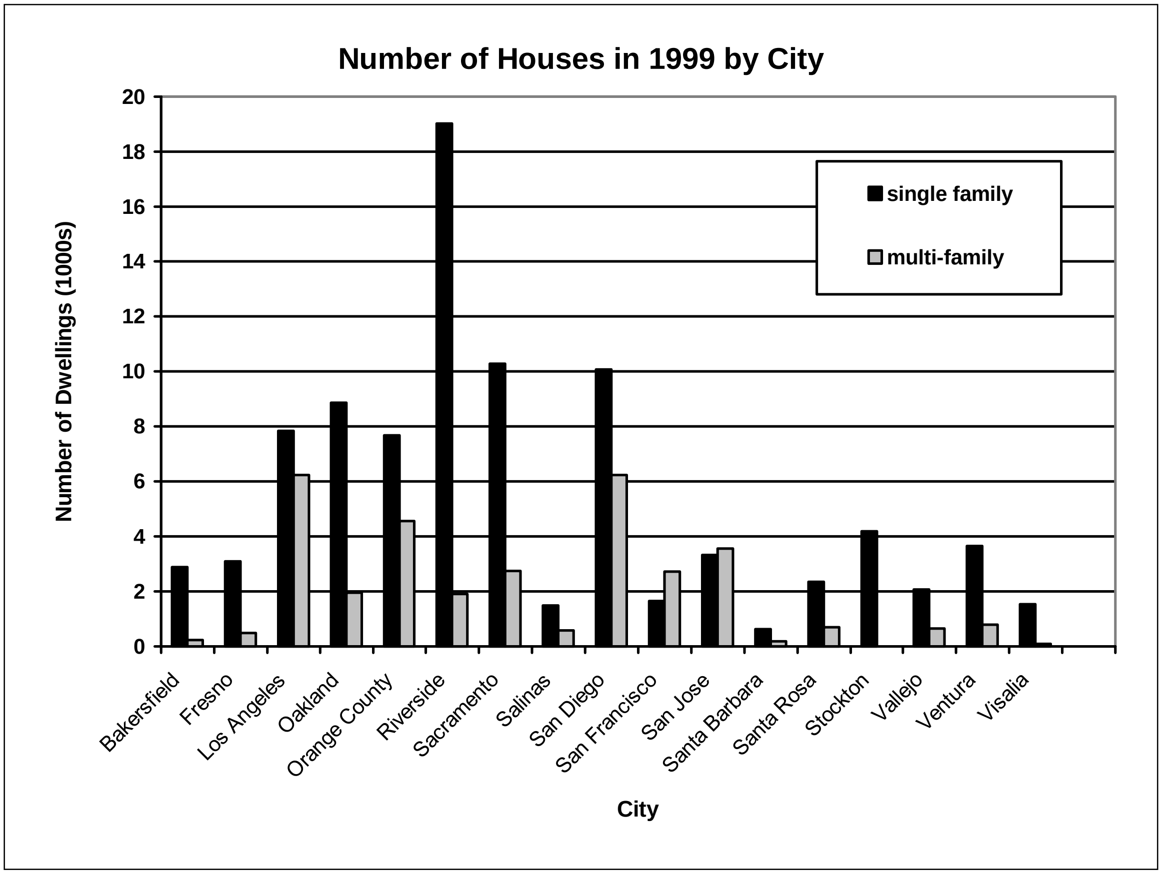


Figure 4: Number of Dwellings Constructed in California in 1999 by City

Over 73 percent of the dwellings constructed in 1999 are single-family dwellings. The majority of the multi-family dwellings are constructed in or near the major cities (i.e. Los Angeles, San Diego, San Jose and San Francisco). The ratio of single-family to multi-family dwellings surveyed in this study reflects the 1999 new dwelling statistics.

3.4. Data Collection Procedure

The audits were performed during construction after the framing was up but before it was enclosed with insulation and drywall. At this stage, the amount of framing can be visually verified, including additional framing not shown on the drawings. The data collection process was

- Identify survey sites
- Arrange access with the builder
- Get dimensioned drawings (if available)
- Visit the site at the appropriate construction phase
- Photograph typical and unique construction details
- Count/measure all framing members and record this information in the ACCESS-based computer program
- Return the data tables to project manager for statistical analysis

3.5. Data Analysis Procedure

This project involves the collection and analysis of a large amount of data – a job well suited to a database program. An ACCESS-based computer program was developed to facilitate data collection and analysis. In essence, the ACCESS program serves as a series of electronic data collection forms and a standardized method for calculating framing factors. Appendix I shows the software screens and user manual. The auditor would take the program (on a laptop computer) to the site and collect and enter the data at one time.

The ACCESS computer program offered several advantages over manual data collection. First, the data collection and data entry was done on site, thereby reducing time and potential for errors in recording the data and transferring it from field notes. Second, some data analysis can be done on site for the dwelling being inspected. Thus, the auditor gets immediate feedback on the results for the dwelling. If one or more of the calculated quantities looks unreasonable, the auditor can re-check the data on site. Third, a set of standardized input forms helped to reduce differences in data collection procedures over the survey period.

The auditors entered data for individual dwellings. Their audit results were sent to the project manager for review, amalgamation and computation of the important framing characteristics. The program is able to aggregate and disaggregate the information as needed.

3.6. Framing Factor Definitions

The ACCESS computer program calculates a range of dwelling framing characteristics. The definitions of these framing factors are given below.

Ceiling Framing Factor: ratio of framing area in insulated ceilings to the ceiling area (either gross or net). Framing includes joists, trusses, blocking and framing around skylights and attic hatches that partially or fully penetrate the insulation. Rim joists are not included.

Ceiling Opening to Ceiling Area: ratio of the opening areas in the ceiling to the gross ceiling area (including skylights and access hatches).

Corner Height to Wall Area: ratio of the total height of all corners in insulated walls to the wall area in units of inches per square foot. This is used as a measure of the complexity of the floor plan.

Door Area to Wall Area: ratio of the rough door opening area to the gross wall area (including window and door areas). Swinging and sliding glass doors are considered doors. The reader should note that the door area may include transom or sidelight windows.

Floor Framing Factor: ratio of framing area in insulated floors to the floor area (either gross or net). Framing includes joists, blocking and framing around access hatches that penetrate the insulation. Rim joists are not included.

Floor Opening to Floor Area: ratio of the opening areas in the floor to the gross floor area (including access hatches).

Gross Insulated Ceiling Area: surface area (in the direction perpendicular to heat flow) of all insulated ceilings between heated areas and the outside or unheated areas (such as attics). The ceiling area is based on exterior or outside ceiling dimensions. The ceiling dimensions are to the outside of the framing and include the area of any skylights or attic hatches.

Gross Insulated Floor Area: surface area (in the direction perpendicular to heat flow) of all insulated floors between conditioned spaces and the outside or unconditioned spaces (such as crawlspaces and unheated basements). Non-framed floors such as concrete (e.g. slab on grade) floors are excluded. The floor area is based on exterior or outside floor dimensions. The floor dimensions are to the outside of the framing.

Gross Insulated Wall Area: surface area (in the direction perpendicular to heat flow) of all insulated walls between conditioned spaces and the outside or unconditioned spaces (such as garages and porches). The wall area is based on exterior or outside wall dimensions. The wall width is to the outside of the framing. The wall height is from the bottom of the main floor to the inside of the ceiling framing, including the height of any wall/interior floors junctions (i.e. including rim joists). The area of any windows or doors is included.
Net Insulated Ceiling Area: is the gross ceiling area less the area of any skylights or attic hatches.
Net Insulated Floor Area: is the gross floor area less the area of any floor hatches.
Net Insulated Wall Area: is the gross wall area less the area of windows, doors. The net insulated wall area includes the area of rim joists.
Overall Framing Factor: ratio of all framing areas in the insulated floors, ceilings and walls to the total area of insulated floors, ceilings and walls (either gross or net). Non-framed floors, ceilings and walls (e.g. concrete or solid masonry) are not included in the calculation.
Rim Joist Area to Wall Area: ratio of the rim joist area to the gross wall area
Total Floor Area: total area of all floors (above conditioned & unconditioned spaces). This area is used by builders, realtors and homeowners to describe the size of the dwelling.
Window Area to Wall Area: ratio of the rough window opening area to the gross wall area (including window and door areas). Swinging and sliding glass doors are considered doors.
Wall Framing Factor: ratio of the framing area in the insulated walls to the wall area (either gross or net). Framing includes headers, sill plates, studs, framing around doors and windows, corners, blocking and where floor joists penetrate the wall insulation layer. Framing that does not bridge the insulation (e.g., exterior or interior strapping, let-in bracing, rim joist) is excluded.

4.0 Results of Dwelling Audits

4.1. Distribution of Dwelling Audits

The audits were performed over the period from Fall 2000 to Spring 2001. The results are summarized by seismic zone and dwelling type in Table 5, Table 6, and Table 7 show the distribution of the dwellings characteristics. The data from these dwellings has been analyzed and is presented in the remainder of this section.

Table 5: Number of Dwelling Type by Zone

Dwelling Type	Seismic Zone 3	Seismic Zone 4	Total
Detached	11	19	30
Attached	2	16	18
Multi-unit	4	8	12
Total	17	43	60

Table 6: Single Detached and Attached Dwelling Characteristics

Number of Buildings in Each Zone			
		Seismic Zone 3	Seismic Zone 4
Area	**Under 2400 sq. ft.**	8	30
	Over 2400 sq. ft.	5	5
Stories	**1 Story**	11	9
	2 or more	2	26
	Split	0	0
Basement	**Full**	0	0
	Slab-on-grade	13	35
	Crawlspace	0	0

Table 7 sets out criteria for selecting the 12 multi-family buildings. Since there is less variety in multi-family dwellings than there is in detached and attached dwellings, the only selection criterion for multi-family buildings is area/unit.

Table 7: Multi-Family Dwelling Characteristics

Number of Buildings by Zone			
		Seismic Zone 3	**Seismic Zone 4**
Area	< 1000 sq. ft. / unit	2	5
	> 1000 sq. ft./unit	2	3

4.2. Framing Factors for Detached Dwelling

Table 8 summarizes the framing factors for the 30 detached dwellings. The individual dwelling values are contained in Appendix II. The floor framing factor is labeled as "not available" because none of the surveyed dwellings contained a framed floor. Windows and doors account for 17 percent of the gross wall area. As discussed in Section 3.6, the door area includes swinging and sliding glass doors and door area includes glazed areas around doors (e.g., transoms and sidelites). The net ceiling and wall framing factors are 7 and 26 percent respectively.

Table 8: Framing Factors for Detached Dwellings (%, unless noted)[1]

Component	Zone 3	Zone 4	All
Area and Length Ratios			
Window Area to Wall Area	**12.8** ± 2.8	**11.2** ± 4.1	**11.8** ± 3.8
Door Area to Wall Area	**6.2** ± 3.0	**4.5** ± 1.4	**5.1** ± 2.2
Corner Height to Wall Area (inches/ft^2)	**0.5** ± 0.2	**0.5** ± 0.1	**0.5** ± 0.1
Exposed Perimeter to Floor Area (inches/ft^2)	**0.5** ± 0.2	**0.4** ± 0.2	**0.4** ± 0.2
Ceiling Opening to Wall Area	**0.3** ± 0.2	**0.4** ± 0.2	**0.4** ± 0.2
Floor Opening to Floor Area	**0.0** ± 0.0	**0.0** ± 0.0	**0.0** ± 0.0
Framing Factors Based on Gross Areas			
Ceiling	**7.2** ± 1.4	**6.7** ± 0.5	**6.9** ± 0.9
Wall	**22.3** ± 2.2	**21.1** ± 2.0	**21.6** ± 2.1
Floor	**Not Available**	**Not Available**	**Not Available**
Overall	**11.7** ± 1.6	**11.5** ± 2.0	**11.6** ± 1.8
Framing Factors Based on Net Areas			
Ceiling	**7.2** ± 1.4	**6.7** ± 0.5	**6.9** ± 0.9
Wall	**27.6** ± 2.9	**25.2** ± 3.3	**26.1** ± 3.3
Floor	**Not Available**	**Not Available**	**Not Available**
Overall	**13.3** ± 2.2	**12.9** ± 2.7	**13.0** ± 2.5

[1] + or - values indicate one standard deviation

4.3. Framing Factors for Attached Dwelling

Table 9 summarizes the framing factors for the 18 attached dwelling surveys. Appendix II contains the individual values. The results are similar to those for detached dwellings. The percentage of windows and doors is slightly higher at 19 percent because the common wall reduces the exterior wall area. Nevertheless, the net ceiling and wall framing factors are almost identical at 7 and 27 percent.

Table 9: Framing Factors for Attached Dwellings (%, unless noted)[1]

Component	Zone 3	Zone 4	All
Area and Length Ratios			
Window Area to Wall Area	**12.1** ± 0.4	**12.0** ± 3.1	**12.0** ± 3.2
Door Area to Wall Area	**9.0** ± 4.2	**6.6** ± 2.6	**6.9** ± 2.7
Corner Height to Wall Area (inches / ft^2)	**0.7** ± 0.1	**0.8** ± 0.3	**0.8** ± 0.3
Exposed Perimeter to Floor Area (inches / ft^2)	**0.0** ± 0.0	**0.2** ± 0.1	**0.2** ± 0.1
Ceiling Opening to Wall Area	**0.4** ± 0.4	**0.6** ± 0.3	**0.6** ± 0.3
Floor Opening to Floor Area	**0.0** ± 0.0	**0.0** ± 0.0	**0.0** ± 0.0
Framing Factors Based on Gross Area			
Ceiling	**6.9** ± 0.7	**7.4** ± 1.2	**7.3** ± 1.1
Wall	**18.0** ± 0.2	**22.0** ± 1.2	**21.6** ± 1.3
Floor	**Not Available**	**Not Available**	**Not Available**
Overall	**9.4** ± 1.1	**12.6** ± 2.9	**12.2** ± 2.8
Framing Factors Based on Net Area			
Ceiling	**6.9** ± 0.7	**7.4** ± 1.2	**7.4** ± 1.1
Wall	**22.8** ± 1.3	**27.1** ± 2.1	**26.7** ± 1.3
Floor	**Not Available**	**Not Available**	**Not Available**
Overall	**10.5** ± 1.7	**14.4** ± 3.6	**14.0** ± 3.5

[1] = or - values indicate one standard deviation

4.4. Framing Factors for Multi-Unit Dwelling

Table 10 summarizes the results for the 12 multi-family dwelling surveys. Appendix II contains the individual dwelling values. The ceiling and wall framing factors for the multi-family dwellings are almost identical to those for attached and detached dwellings.

Zone Four has higher seismic loading requirements, so it was expected that dwellings in Zone Four would have higher framing factors than dwellings in Zone Three. Surprisingly, the framing factors of these zones are very similar for all three housing types.

Table 10: Framing Factors for Multi-Family Dwellings (%, unless noted)[1]

Component	Zone 3	Zone 4	All
Area and Length Ratios			
Window Area to Wall Area	**10.0** ± 7.5	**11.1** ± 2.5	**10.8** ± 4.6
Door Area to Wall Area	**8.1** ± 1.4	**11.1** ± 3.0	**10.1** ± 2.9
Corner Height to Wall Area (inches/ft^2)	**0.9** ± 0.2	**0.9** ± 0.1	**0.9** ± 0.2
Exposed Perimeter to Floor Area (inches/ft^2)	**0.7** ± 0.3	**0.5** ± 0.1	**0.6** ± 0.2
Ceiling Opening to Wall Area	**0.3** ± 0.3	**0.5** ± 0.2	**0.4** ± 0.3
Floor Opening to Floor Area	**0.0** ± 0.0	**0.0** ± 0.0	**0.0** ± 0.0
Framing Factors Based on Gross Areas			
Ceiling	**6.7** ± 0.6	**7.0** ± 2.8	**6.9** ± 2.3
Wall	**20.7** ± 0.4	**21.7** ± 0.9	**21.4** ± 1.3
Floor	**Not Available**	**Not Available**	**Not Available**
Overall	**16.6** ± 0.5	**17.5** ± 1.6	**17.2** ± 2.1
Framing Factors Based on Net Areas			
Ceiling	**6.7** ± 0.9	**6.6** ± 3.0	**6.7** ± 2.5
Wall	**25.4** ± 2.3	**28.1** ± 2.2	**27.2** ± 2.5
Floor	**Not Available**	**Not Available**	**Not Available**
Overall	**19.8** ± 0.9	**21.9** ± 2.4	**21.2** ± 2.9

[1] + or - values indicate one standard deviation

4.5. Analysis of Framing Factors

Sections 4.2 to 4.4 presented the framing factors as a function of dwellings type and region. In this section, the effect of other dwelling characteristics on framing factors is studied, specifically floor area and number of stories.

Figure 5, Figure 6, and Figure 7 show the overall net framing factor as a function of total floor area. The overall framing percentage varies from 9 to 18 percent for detached dwellings, however, there appears to be no correlation between dwelling size and the amount of framing. The same result seems to apply for attached and multi-family dwellings. Overall framing factors range from 10 to 23 percent and 8 to 24 percent respectively. Neither shows a strong relationship between framing factor and dwelling size.

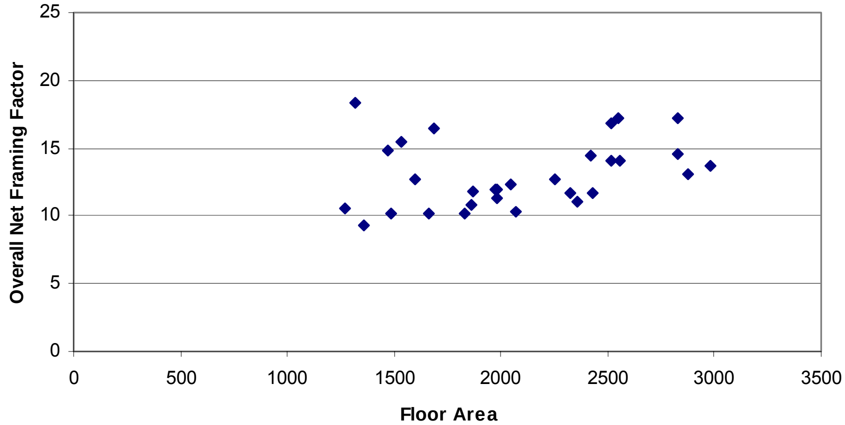


Figure 5: Overall Net Framing Factors vs. Floor Area for Detached Dwellings

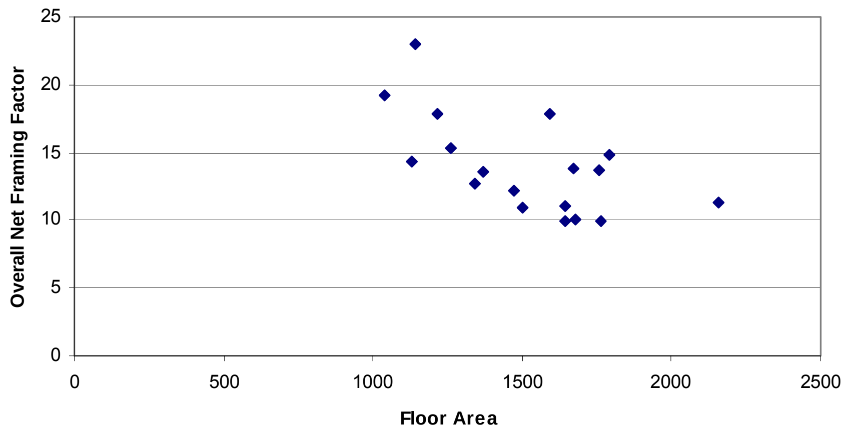


Figure 6: Overall Net Framing Factors vs. Floor Area for Attached Dwellings

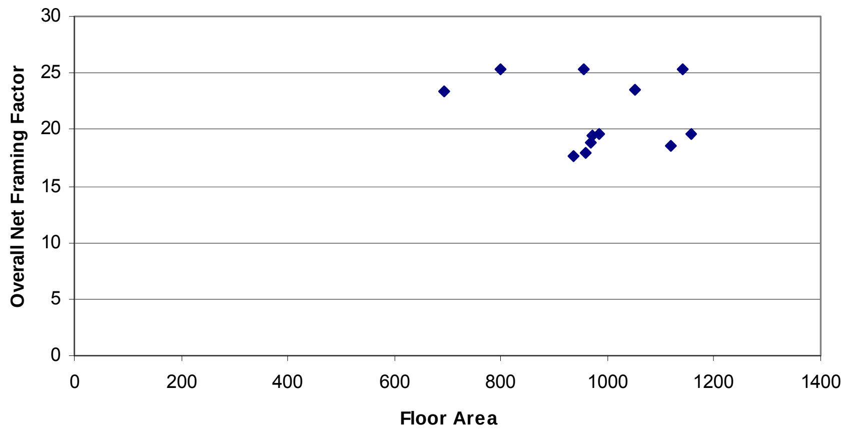


Figure 7: Overall Net Framing Factors vs. Floor Area for Multi-Family Dwellings

Ceilings and floors tend to have lower framing factors than walls. As a result, the area of ceilings and exposed floors (e.g. above garages) can dramatically affect overall framing factors. Therefore, the relationships between wall framing factors and various building characteristics may be evident. Figure 8, Figure 9, and Figure 10 illustrate the relationship between floor area and wall net framing factor. The wall net framing factors range from 19 to 33 percent, 22 to 32 percent and 24 to 34 percent for detached, attached and multi-family dwellings respectively. Correlation analysis indicates that there is a relationship between wall net framing factor and floor area for detached dwellings (correlation coefficient of 0.62), but not attached and multi-family dwellings.

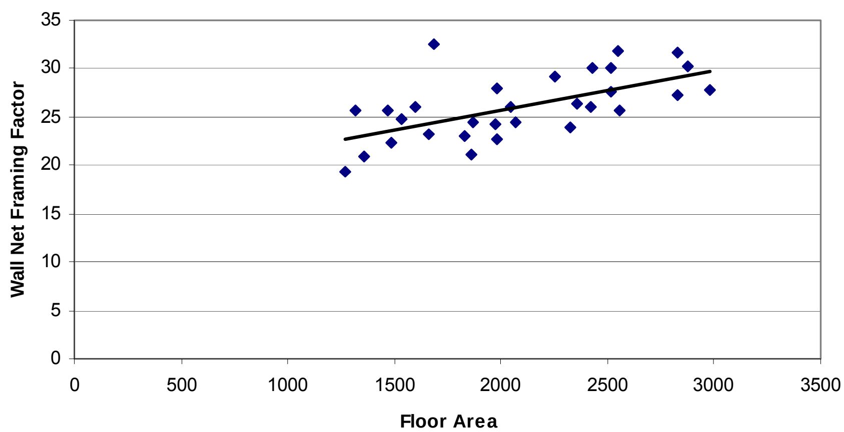


Figure 8: Wall Net Framing Factors vs. Floor Area for Detached Dwellings

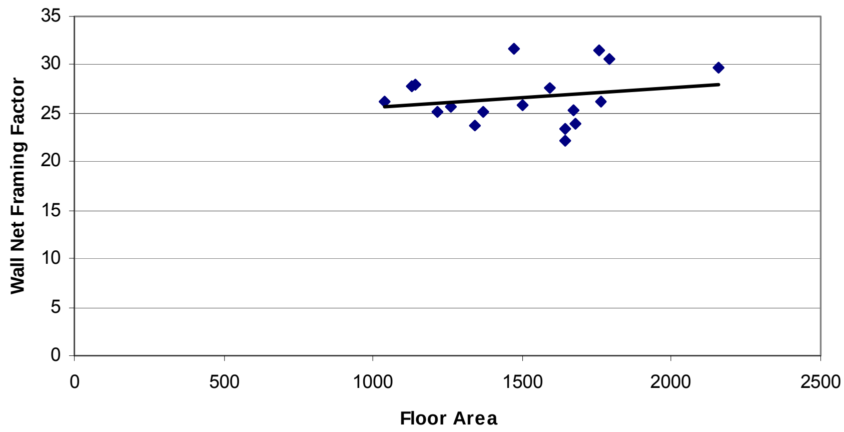


Figure 9: Wall Net Framing Factors vs. Floor Area for Attached Dwellings

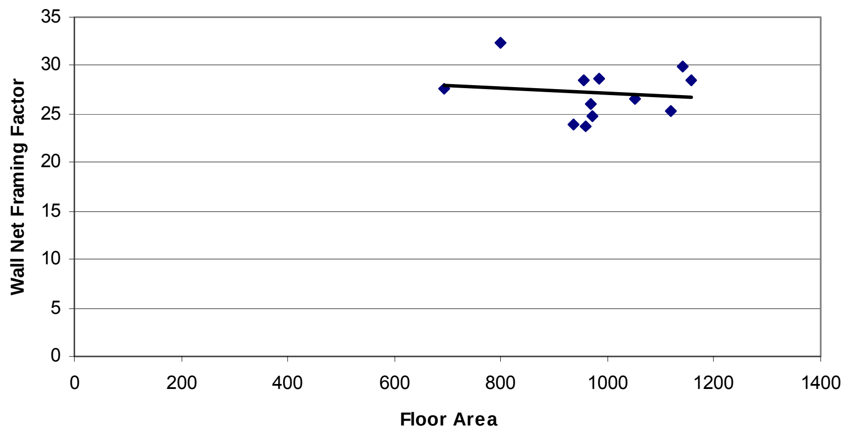


Figure 10: Wall Net Framing Factors vs. Floor Area for Multi-Family Dwellings

Figure 11 shows the effect of the number of stories on overall net framing factor. The framing factor increases with the number of stories with an average of 13, 16 and 23 percent for one, two, and three story dwellings. There are two reasons for this increase. First, single story dwellings have a larger ceiling area than multi-story buildings. Because ceilings have a low framing factor, increasing the ceiling area decreases the overall framing factor. Second, for multi-story dwellings, the amount of wall framing in lower floors is increased in order to carry the weight of the floors above. For example, some dwellings had studs spaced on 12-inch centers for the first floor and on 16-inch centers for the upper floors.

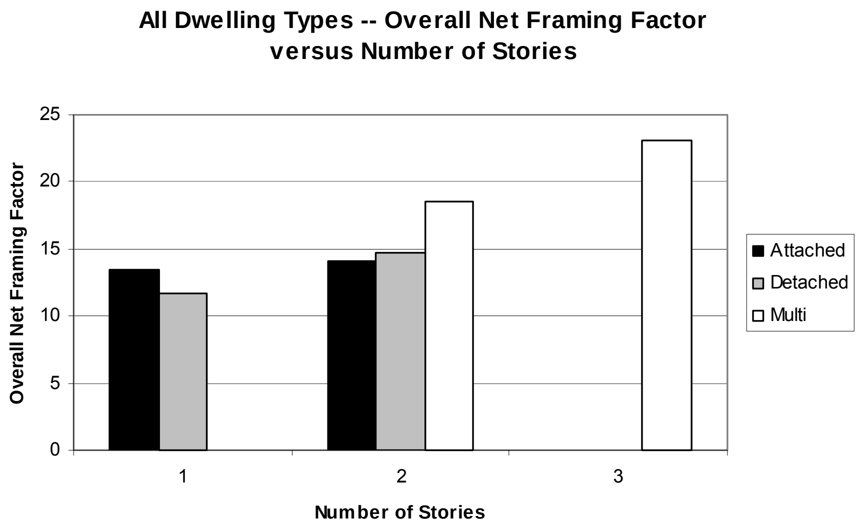


Figure 11: Effect of Number of Stories on Overall Framing Factors

A similar trend is evident in Figure 12, which compares number of stories and wall net framing factor. The increase in framing factor with number of stories is smaller because the effect of the ceiling has been removed.

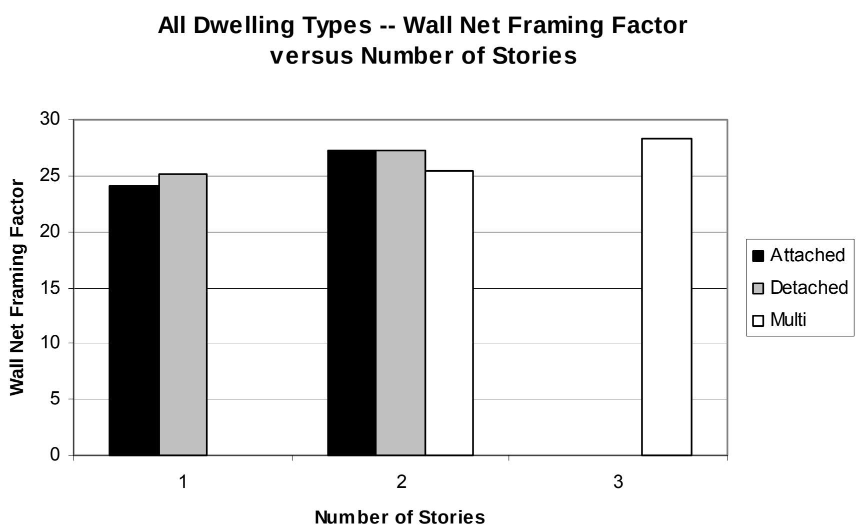


Figure 12: Effect of Number of Stories on Wall Framing Factor

The corner height to wall area ratio provides a measure of the complexity of the floor plan. A simple rectangular floor plan will only have four corners, while a more complicated, “H-shaped” plan would have 12 corners and a higher ratio. Because more framing is required at corners, it is reasonable that there may be a relationship between wall framing factor and corner height. However, Figure 13, Figure 14, and Figure 15 do not indicate any relationship.

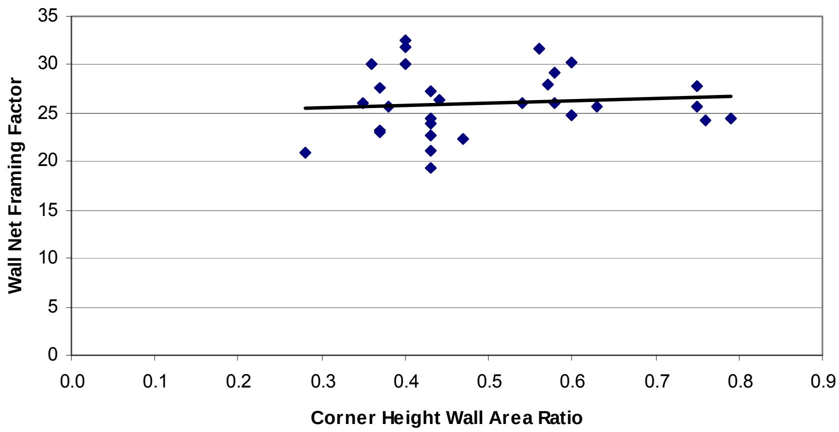


Figure 13: Wall Net Framing Factor vs. Corner Height to Wall Area Ratio for Detached Dwellings

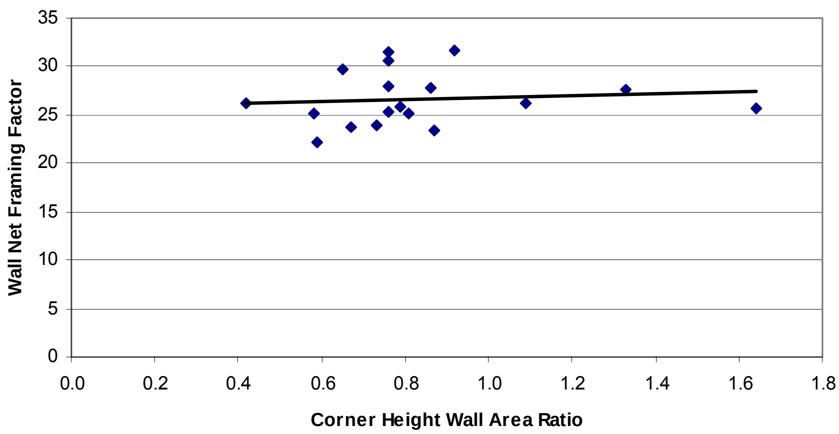


Figure 14: Wall Net Framing Factor vs. Corner Height to Wall Area Ratio for Attached Dwellings

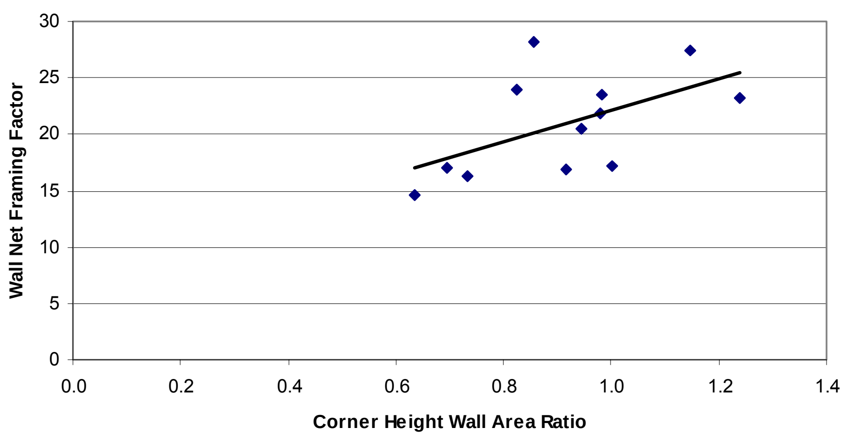


Figure 15: Wall Net Framing Factor vs. Corner Height to Wall Area Ratio for Multi-Family Dwellings

Window and door openings require that lintels (headers), king-studs, jack-studs and cripple studs be provided to distribute wind loads and gravity loads from above the openings. These pieces of lumber increase the amount of framing that goes into a wall, increasing the framing factor. Figure 16, Figure 17, and Figure 18 all show a relationship between wall net framing factor and the sum of the window to wall area and the door to wall area ratios. Correlation analysis indicates that this dwelling characteristic has the strongest relationship with wall net framing factor.

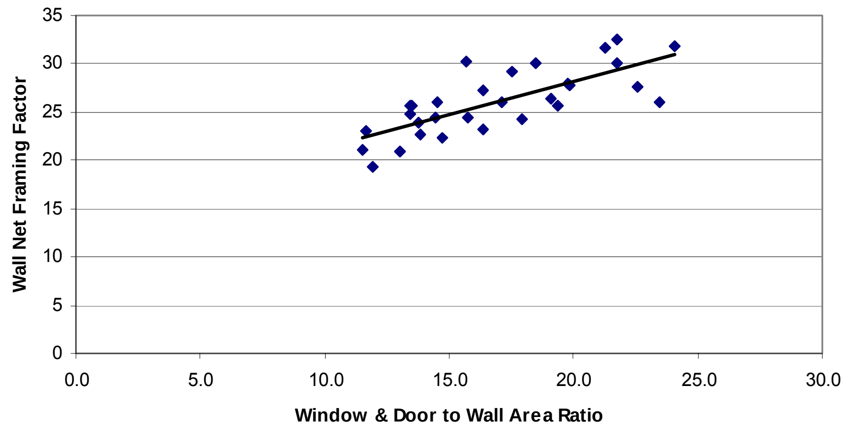


Figure 16: Wall Net Framing Factor vs. Window + Door to Wall Area Ratio for Detached Dwellings

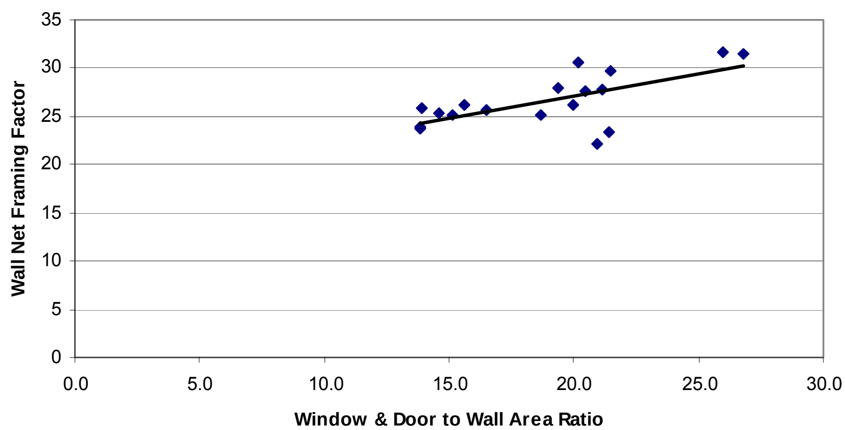


Figure 17: Wall Net Framing Factor vs. Window + Door to Wall Area Ratio for Attached Dwellings

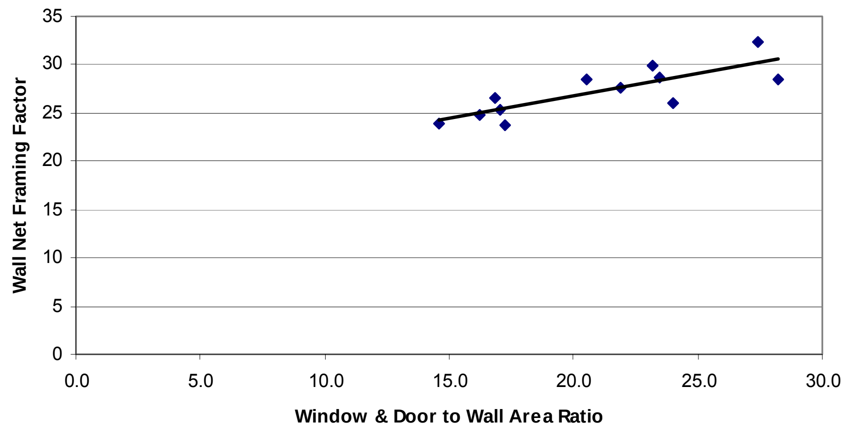


Figure 18: Wall Net Framing Factor vs. Window + Door to Wall Area Ratio for Multi-Family Dwellings

In the ASHRAE study, the effect of dwelling characteristics on framing factors was also studied. No correlation was found between dwelling size and the amount of framing. Furthermore, in the ASHRAE study there was less change in framing factor with number of stories. In addition to studying the effect of floor area and number of stories, the ASHRAE study looked at type of wall framing (2X4 or 2X6).

Some structural and economic arguments have been made to support the use of 2x6 framing on 24 inch spacing. However, most of the dwellings surveyed used 2X4 studs on 16 inch spacing for the wall framing, with the remainder using 2X6 studs on 16 inch spacing. In many cases, a combination of the two stud sizes is used to deal with unique or difficult framing details. The ASHRAE study showed that there is very little difference in wall framing factor between the two stud sizes. A review of the individual files showed that 2X6 studs were used more for structural reasons such as high ceilings than to take advantage of a wider stud spacing (e.g., 24 inch centers). The same result applies to the California study, since all of the dwellings were framed with studs on 16-inch centers. No comment can be made on framing factors for 24-inch stud spacing because of the lack of data for 24-inch spacing in both the ASHRAE and California studies.

Based on the analysis that accompanies Figures 5 to 18 and a review of the individual survey files, it would appear that window and door openings, floor area and number of stories all have an influence on the wall net framing factor. Relationships between these dwelling characteristics and the overall net framing factor are not always as obvious, and there is not a single dominant characteristic that defines either the wall or overall framing factor. Site observations indicate that there are many characteristics that affect the framing factors including:

- building type (i.e. detached, attached, multi),
- number and size of openings (e.g., windows and doors),
- floor area,
- number of stories,
- type of wall framing (2X4 or 2X6),
- architectural complexity,
- builder practices (e.g., 2-stud vs. 3-stud corners)

It is the combination of all the characteristics listed above which results in the variation in framing factors. Although not discussed in this report, architectural complexity and builder practices may have the largest impact on framing factor. There is a wide range in framing factors for the different builders, however, the framing factors for two different, but architecturally similar, dwelling plans from the same builder showed little variation. In the ASHRAE study, five of the eight pairs of dwellings framed by the same builder have wall framing factors within one percent. Framers tend to learn on the job in small groups and there is no standardized method for framing. In addition, small architectural details (e.g., framing around a bay window) can greatly increase the amount of framing.

4.6. Statistical Confidence

Given the small sample size of this study, it is useful to estimate how well the data represents the greater population of dwellings in California. Table 11 summarizes the expected range for mean framing factors at 95 percent confidence. In other words, one can be 95 percent confident that another study of framing would produce mean framing factors within the ranges given in the table. For example, the mean of the detached wall net framing factors would fall somewhere between 24.9 percent and 27.3 percent. Since the ranges are relatively tight, the samples represent the greater population well.

Table 11: Range for Mean Net Framing Factors at 95% Confidence

Component	Detached	Attached	Multi-Family
Ceiling	6.6 to 7.2	6.9 to 7.9	5.3 to 8.1
Wall	24.9 to 27.3	25.6 to 27.8	25.8 to 28.6
Floor	Not Available	Not Available	Not Available
Overall	12.1 to 13.9	12.4 to 15.6	19.6 to 22.8

5.0 Comparison to ASHRAE Results

Table 12 compares the California results with the national results from the ASHRAE project [Enermodal, 2001]. Dwellings throughout North America are made stable by framing within the buildings. It was expected that dwellings in high seismic regions would have higher framing factors than other dwellings, yet Table 12: shows that the framing factors of buildings in high seismic regions -- zones three and four of California -- are almost identical to those of other buildings in the Northeast, Midwest, South, and West regions of the United States. Ceiling, wall, and overall framing factors are within one standard deviation of each other for both the California Energy Commission and the ASHRAE results.

The framing factor for floors in California is not available because the dwellings surveyed in that area have concrete slab-on-grade floors.

Table 12: California Results Compared to ASHRAE Results (all values in %)[1]

Component	ASHRAE (National) Results	California Results
Window Area to Gross Wall Area	**11.5** ± 4.7	**11.6** ± 3.8
Door Area to Gross Wall Area	**5.2** ± 3.7	**6.7** ± 3.3
Rim Joist Area to Gross Wall Area	**4.3** ± 3.3	**Not Available**
Framing Factors	Net	Net
Ceiling	**6.9** ± 2.1	**7.0** ± 1.5
Wall	**25.4** ± 4.5	**26.5** ± 3.0
Floor	**11.9** ± 5.1	**Not Available**
Overall	**15.5** ± 3.8	**14.9** ± 4.3

[1]+ or - values indicate one standard deviation

6.0 Conclusions and Recommendations

6.1. Conclusions

Audits of 60 dwellings were conducted in two seismic regions for three dwelling types. The following conclusions can be drawn about framing in dwellings.
The following conclusions can be drawn about framing in dwellings.

- Approximately 18 percent of the gross wall area is taken up by openings for windows and doors. The amount of openings in floors and ceilings is negligible (less than one percent of the gross area)

The framing factors for attached, detached and multi-family dwellings are very similar and can be represented by a single set of values

- There is very little difference in the framing factors for seismic zones three and four. A single set of values can represent both regions

Table 13 summarizes the framing factors found in the California and the ASHRAE (national) studies. The results are very similar and as such, it appears that little additional framing is used in California to meet the seismic requirements.

Table 13: Recommended Table of Framing Factors (all values in %)

Component	ASHRAE (National) Results	California Results
Window Area to Gross Wall Area	**12**	**12**
Door Area to Gross Wall Area	**5**	**7**
Rim Joist Area to Gross Wall Area	**4**	**Not Available – See Note**
Framing Factors	Net	Net
Ceiling	**7**	**7**
Wall	**25**	**27**
Floor	**12**	**Not Available – See Note**
Overall	**16**	**15**

Note: Since the vast majority of dwellings in the State of California are constructed on slab-on-grade foundations, there is not sufficient framed floor data to calculate framing factors related to the floor. Rim Joist Area is included in the Gross and Net Wall Areas.

6.2. Benefits to the State of California

This study has examined the amount of framing in residential building envelopes. This information improves the ability of engineering and design professionals to determine the effects of insulation strategies on building energy use.

By properly assessing the energy performance of building envelopes, the market will be encouraged to use the insulation strategies that provide optimal benefits. The net effect will be to reduce energy use in new California homes

6.3. Recommendations

Observations made during the site surveys suggest that architectural complexity and builder practices have an impact on the amount of framing used in the construction of low-rise dwellings. As these were not the focus areas in this study, the following are recommended:

- Further research to identify those architectural features that require the most framing and create the largest thermal bridges.
- Efficient framing methods (e.g. stack framing) should be further developed and a formal training program should be established to encourage builders to implement these practices.

7.0 References

ASHRAE, Handbook of Fundamentals, 1997 edition, American Society of Heating Refrigerating and Air-Conditioning Engineers, Atlanta, GA (USA)

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Enermodal, 2001. Characterization of Framing Factors for Low-Rise Residential Building Envelopes (904-RP). Final Report prepared for ASHRAE, Atlanta, GA (USA)

NRCC, 1997. Model National Energy Code for Dwellings, National Research Council of Canada, Ottawa, ON (Canada)

Uniform Building Code, 1997 State of California Edition, International Conference of Building Officials, Whittier, California (USA)

US Census Bureau, Washington, DC (USA)

Appendix I – Procedure for Dwelling Data Collection

A large amount of data must be collected to establish statistically valid framing factors for wood-framed dwellings. A database program was developed as the basis of the framing survey. Each Dwelling auditor used a copy of the program to enter, store and process survey data. This section explains the format of the data entry forms and outlines the type of data collected.

The flowchart in Figure I - 1 illustrates the relationship between the 11 entry forms that make up the database program. General information about the site is entered in the ***Site Survey*** form; the ***Ceilings***, ***Walls*** and ***Floors*** forms are used to describe the general framing elements that make up the dwelling; and framing details are entered in the ***Openings***, ***Intersections*** and ***Corners*** forms.

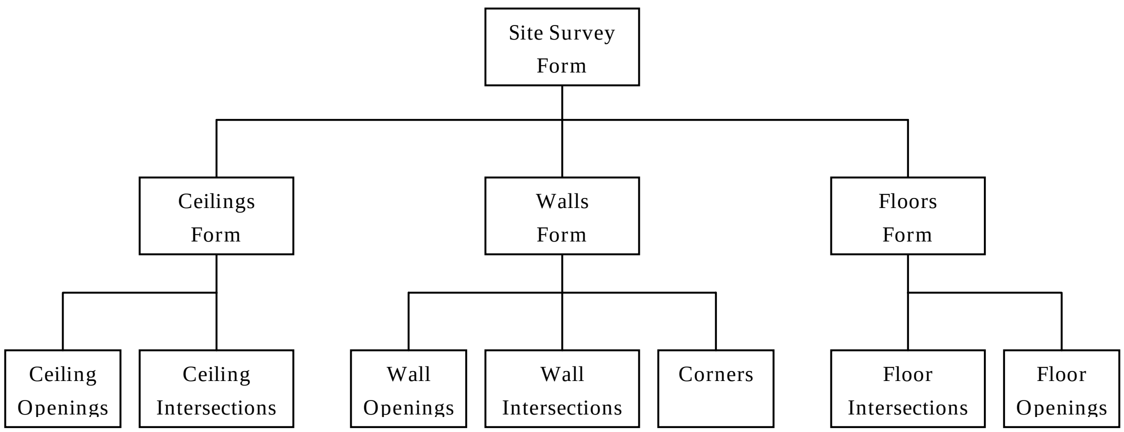


Figure I - 1: Database Structure

The forms that are lower in the database structure shown in Figure I - 1 contain more detail and are accessed from the less detailed forms higher up in the flowchart. Surveyors will work from general to specific (i.e., down the flowchart) when entering data. The program will work from specific to general (i.e., up the flowchart) when processing data. Sections 2.1 through 2.4 describe the type of data entered into the database. Section 3 describes how these data are processed to determine the framing factors.

Site Survey Form

The ***Site Survey*** (Figure I - 2) form has three functions: to navigate through the database of survey sites, to summarize general information about each site, and to access the site details in the ***Ceiling***, ***Wall*** and ***Floor*** forms.

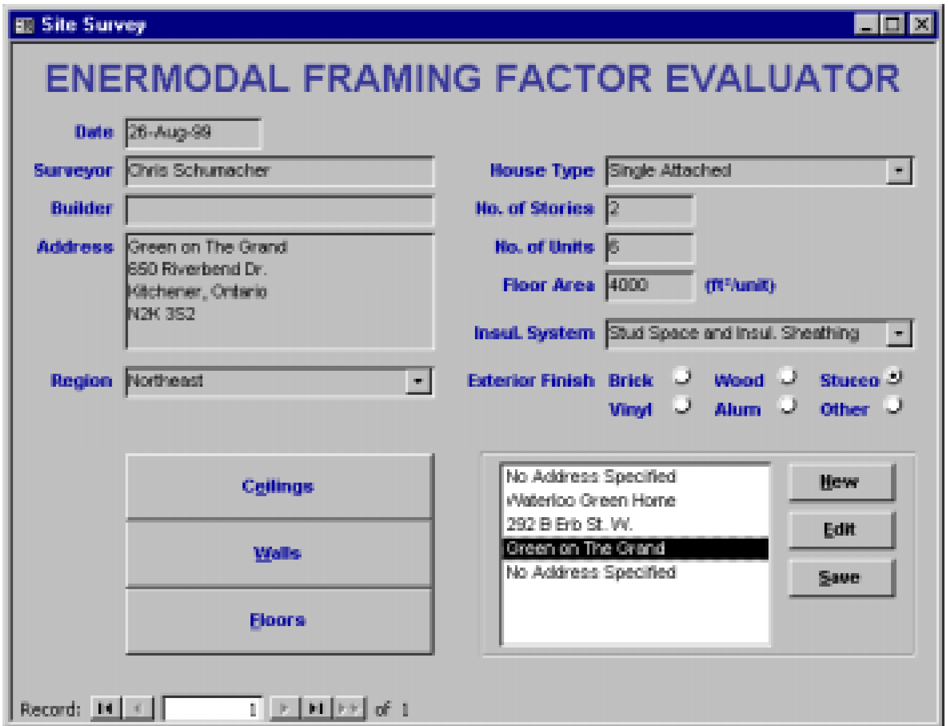


Figure I - 2: Site Survey Form

The program allows the surveyor to navigate through the survey site database using the "Site" list box. The surveyor can add a site by pressing the ***New*** button. When a new site is added, the surveyor is immediately asked to enter the general information for that site:

Date	Enter the date on which the survey was conducted
Surveyor	Enter the name of the surveyor
Builder	Enter the name of the builder
Address	Enter the address of the survey site
Zone	Select the census zone of the survey site: *West, Midwest, Northeast, South*

Dwelling Type Select the type of dwelling:
Single Detached, Single Attached, Multi-Family
If the building is Multi-Family, the surveyor should enter each unit type as a separate site. The sites are related using a similar address. Given a building with, for example, 8 units of one type of layout and 4 units of another, the surveyor would create two sites (e.g., Water St. A and Water St. B). One site would have 8 units and the other would have 4.

No. of Stories Enter the number of stories

No. of Units Enter the number of units if Multi-Family

Floor Area Enter the gross floor area in ft^2 / unit

Insul. System Select the insulation placement used:
Cavity insulation, Insulating sheathing, Cavity & Insul. Sheathing

Exterior Finish Select the exterior wall finish(es) as applicable:
Brick, Wood, Stucco, Vinyl, Aluminum, Other

Once the general information has been entered, the database is updated by pressing the ***Save*** button. The surveyor can make corrections to the general information by selecting a site from the "Site" list box and pressing the ***Edit*** button. If necessary, the surveyor can remove a site from the database by selecting it from the "Site" list box and pressing the ***Delete*** button. All of the forms use similar list boxes to manage the database records.
The surveyor can enter or modify detailed site information by selecting a site from the "Site" list box and pressing one of the ***Ceilings***, ***Walls*** or ***Floors*** buttons. The detailed information forms are explained in the following sections.

Ceiling Form

The ***Ceiling*** form (Figure I - 3) allows the surveyor to enter detailed information about ceiling framing for each site. The information contained on the ***Ceiling*** form describes a ceiling element (i.e., a grouping of similar ceiling joists). A "Ceiling" list box allows the user to navigate through and edit ceiling elements.

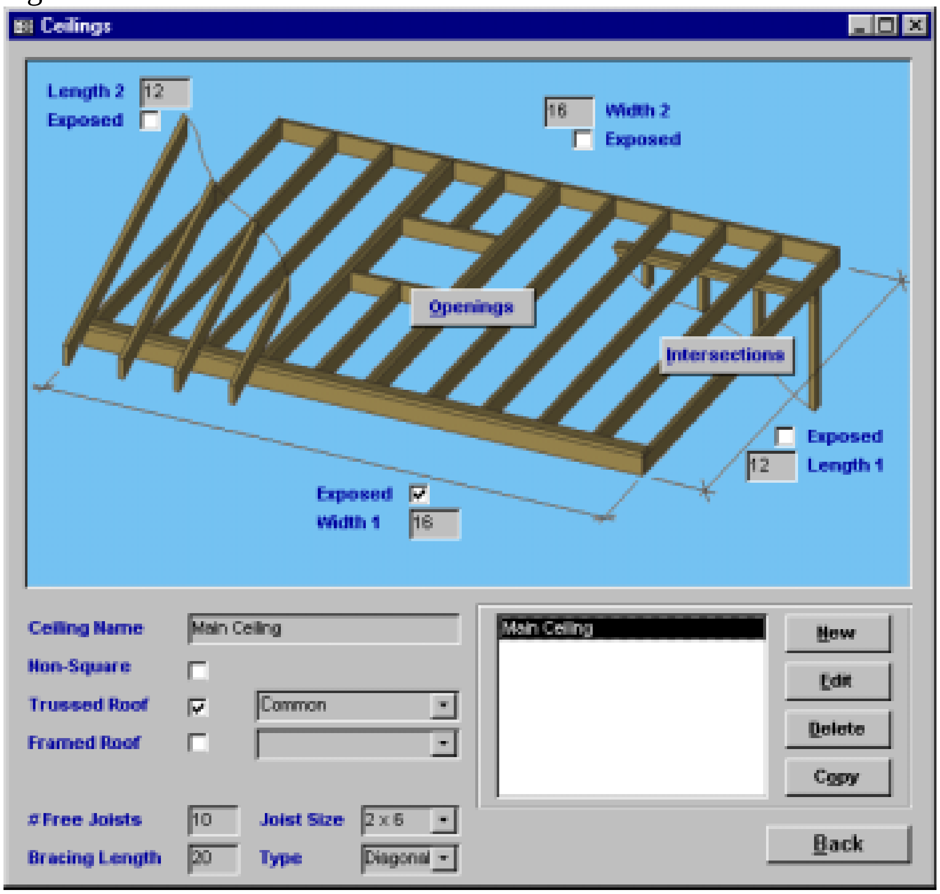
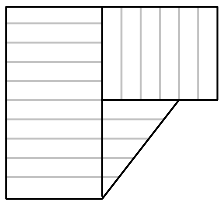


Figure I - 3: Ceiling Form

If the dwelling has more than a simple rectangular ceiling, the surveyor must enter the ceiling as several ceiling elements. The left of Figure I - 4 illustrates a complex ceiling. This ceiling can be entered as four ceiling elements (Figure I - 4 – right). Each element has three or four sides. A 3-sided element must have one right angle corner and a 4-sided element must have two right angle corners. The side of an element can be completely exposed to the exterior (e.g., a ring joist) or can be completely sheltered by another ceiling element. A side cannot be partially exposed and partially sheltered. In the example, ceiling element 2 has one exposed side while ceiling element 3 has three exposed sides. Ceiling elements 2 and 3 could not be combined into one element because one of the sides would be partially exposed and partially sheltered.



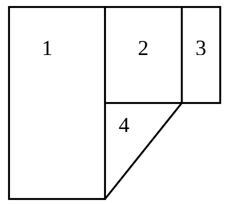


Figure I - 4: Dividing a Ceiling into Ceiling Elements

The surveyor can add a ceiling element by pressing the ***New*** button. When a new ceiling element is added, the surveyor is immediately asked to enter the details for that ceiling element.

Name	Enter a name for the ceiling element
Non-square	Check this box if the ceiling element is not rectangular
Length	Enter the length of the ceiling element. The length is measured parallel to the span of the joists.
Width	Enter the width of the ceiling element. The width is measured perpendicular to the span of the joists.
Exposed	Check the exposed box on each side of the ceiling that is exposed to the exterior (i.e. a ring joist).
Trussed Roof	Check this box if the ceiling is beneath a trussed roof, and select the type of truss used: *Common, Scissor, Raised Heel, Parallel, Cantilever, Dropped Chord*
Framed Roof	Check this box if the ceiling is beneath a framed roof, and select the type of bearing for the rafters & ceiling joists: *Vaulted, Top Plate, Rafter Plate*
# Free Joists	Enter the number of free joists in the ceiling element. Free joists are joists that are NOT part of the framing around an opening and are NOT ring joists.

Joist Size	Select the size of the joists used: *2 x 6, 2 x 8, 2 x 10, 2 x 12, 12 Wood-I, 14 Wood-I, 16 Wood-I*
Bracing Length	Enter the total length of the bracing. If there is more than one row of bracing, enter the sum of the lengths of the individual rows.
Bracing	Select the type of bracing used: *Blocking, Cross Bracing, Let-In, Diagonal Bracing, Strapping*

Once this information has been entered, the database is updated by pressing the ***Save*** button. The surveyor can make corrections to the information in a ceiling element by selecting it from the “Ceiling” list box and pressing the ***Edit*** button. If necessary, the surveyor can remove a ceiling element from the database by selecting it from the “Ceiling” list box and pressing the ***Delete*** button.

The surveyor must enter details about the ceiling openings and intersections. This is done in the forms accessed by the ***Openings*** and ***Intersections*** buttons.

Ceiling Openings Form

The ***Ceiling Openings*** (Figure I - 5) form is used to describe the framing around openings such as attic accesses and skylights. A “Ceiling Openings” list box is used to manage ceiling opening elements.

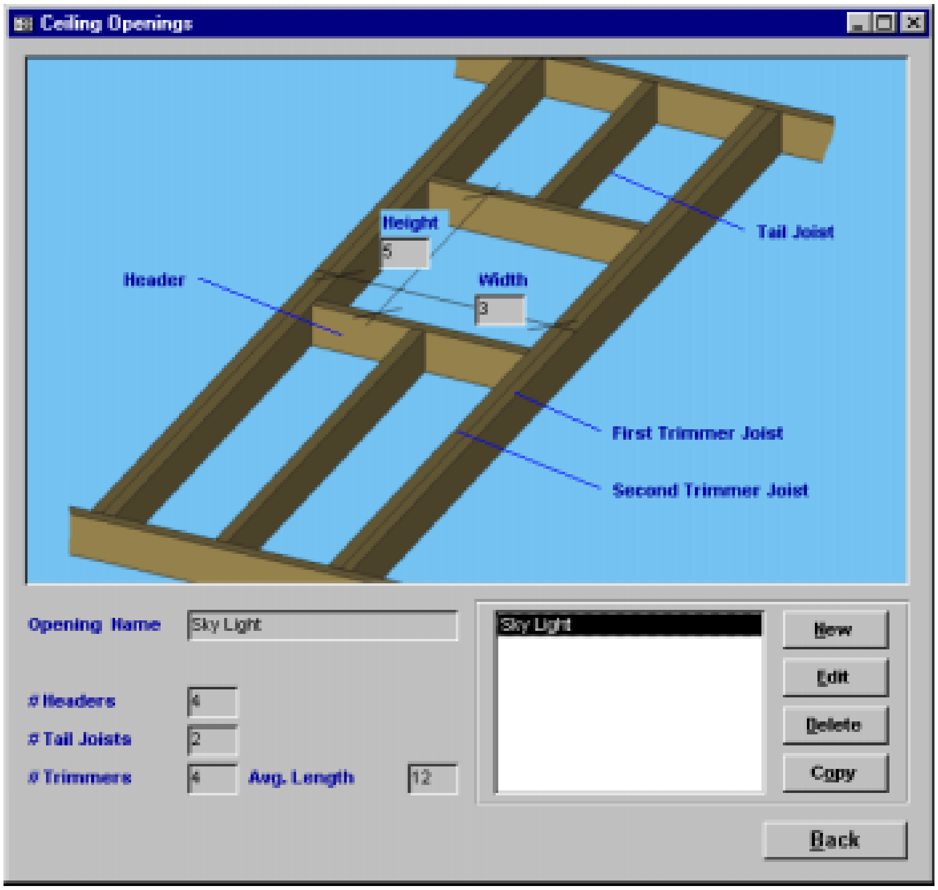


Figure I - 5: Ceiling Openings Form

Several details are necessary to describe each ceiling opening:

Name	Enter a name for the ceiling opening.
Height	Enter the height of the rough ceiling opening.
Width	Enter the width of the rough ceiling opening.
# Headers	Enter the total number of headers included in the ceiling opening. Count all headers above and below the opening.
# Tail Joists	Enter the total number of tail joists included in the ceiling opening. Count all tail joists above and below the opening.

 # Trimmers Enter the total number of trimmer joists included in the ceiling opening. Count all trimmer joists on both sides of the opening.

Avg. Length Enter the average length of the trimmers.

Ceiling Intersections Form

The ***Ceiling Intersections*** (Figure I - 6) form is used to describe the framing at intersections between the ceiling elements and interior walls. The surveyor can manage the ceiling intersection elements using the "Ceiling Intersections" list box.

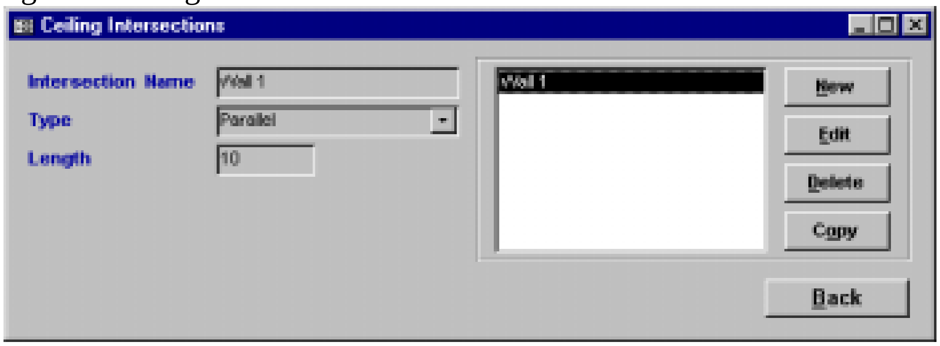


Figure I - 6: Ceiling Intersections Form

Few details are needed to describe a ceiling intersection:

Name	Enter a name for the ceiling intersection.
Type	Select the type of intersection: *Parallel (i.e., in the direction of the joists), Perpendicular*
Length	Enter the length of the intersection.

Wall Form

The ***Wall*** form (Figure I - 7) allows the surveyor to enter detailed information about wall framing for each site. The information contained on the ***Wall*** form describes a wall element (a grouping of similar wall studs). A “Wall” list box allows the user to navigate through and edit wall elements.

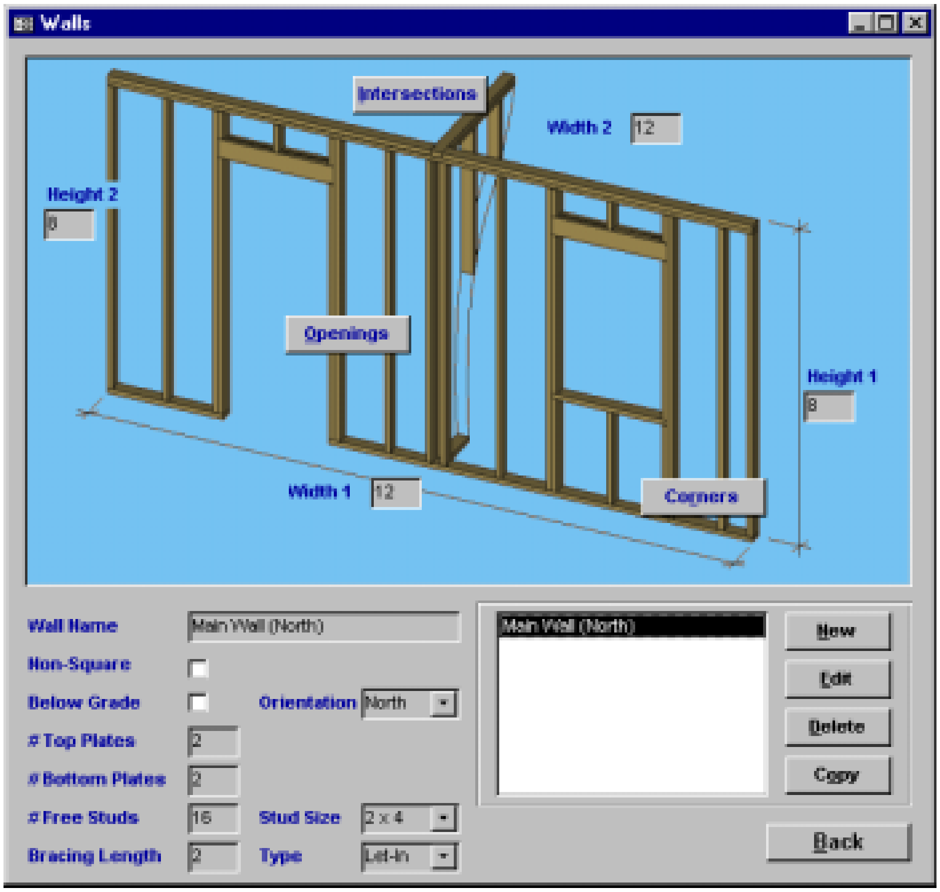


Figure I - 7: Wall Form

Like ceiling elements, wall elements can be 3- or 4-sided. However, since walls are more complicated than ceilings, more details are required to describe a wall element:

Name Enter a name for the wall element

Non-square Check this box if the wall element is not rectangular

Height Enter the height of the wall element. The height is measured parallel to the direction of the studs.

Width Enter the width of the wall element. The width is measured perpendicular to the direction of the studs.

Below Grade Check this box if the wall is below grade (i.e., a basement wall).

Orientation	Select the orientation of the wall element: *N, NE, E, SE, S, SW, W, NW.*
# Top Plates	Enter the number of top plates in the wall element.
# Bottom Plates	Enter the number of bottom plates in the wall element.
# Free Studs	Enter the number of free studs in the wall element. Free studs are studs that are NOT part of the framing around an opening or part of the framing at a corner.
Stud Size	Select the size of the joists used: *2 x 4, 2 x 6*
Bracing Length	Enter the total length of the bracing in the wall element. If there is more than one row of bracing, enter the sum of the lengths of the individual rows.
Type	Select the type of bracing used: *Blocking, Cross Bracing, Let-In, Diagonal Bracing, Strapping*

The database is updated by pressing the ***Save*** button. The surveyor can make corrections to the information in a wall element by selecting it from the "Wall" list box and pressing the ***Edit*** button. If necessary, the surveyor can remove a wall element from the database by selecting it from the "Wall" list box and pressing the ***Delete*** button.
The surveyor must also enter details about the wall openings, intersections and corners. This is done in the forms accessed by the ***Openings, Intersections*** and ***Corners*** buttons.

Wall Openings Form

The ***Wall Openings*** (Figure I - 8) form is used to describe the framing around openings such as windows and doors. A “Wall Openings” list box is used to manage wall opening elements.

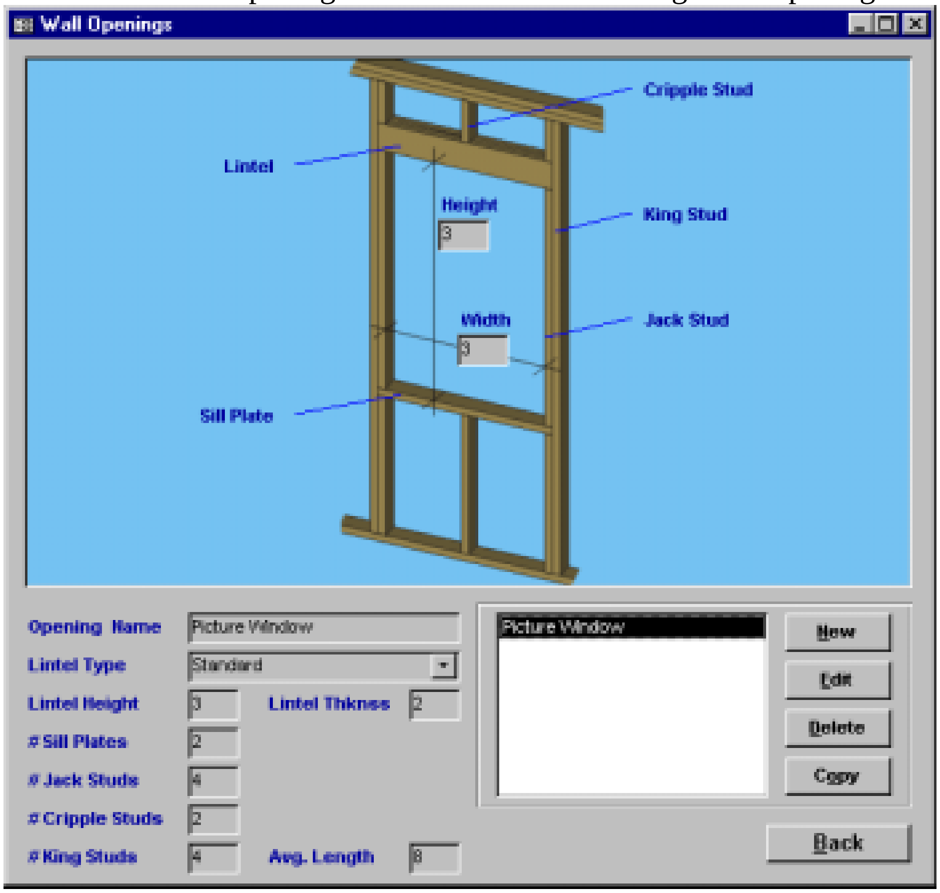


Figure I - 8: Wall Openings Form

Several details are necessary to describe each wall opening:

Name	Enter a name for the wall opening.
Height	Enter the height of the rough wall opening.
Width	Enter the width of the rough wall opening.
Lintel Type	Select the type of lintel used above the wall opening: *Single, Built-Up, Glu-Lam, Double, Double Insulated*
Lintel Height	Enter the total height of the lintel.
Lintel Thknss	Enter the total thickness of the lintel (measured from inside to outside).

 # Sill Plates Enter the total number of sill plates at the bottom of the wall opening. If there are no sill plates, the opening is assumed to be a door, otherwise it is assumed to be a window.

 # Jack Studs Enter the total number of jack studs included in the wall opening. Count the jack studs on both sides of the opening.

 # Cripple Studs Enter the total number of cripple studs in the wall opening. Count all cripple studs above and below the opening.

 # King Studs Enter the total number of king studs included in the wall opening. Count the king studs on both sides of the opening.

Avg. Length Enter the average length of the king studs.

Wall Intersections Form

The ***Wall Intersections*** (Figure I - 9) form is used to describe the framing at intersections between the wall elements and interior walls. The surveyor can manage the wall intersection elements using the "Wall Intersections" list box.

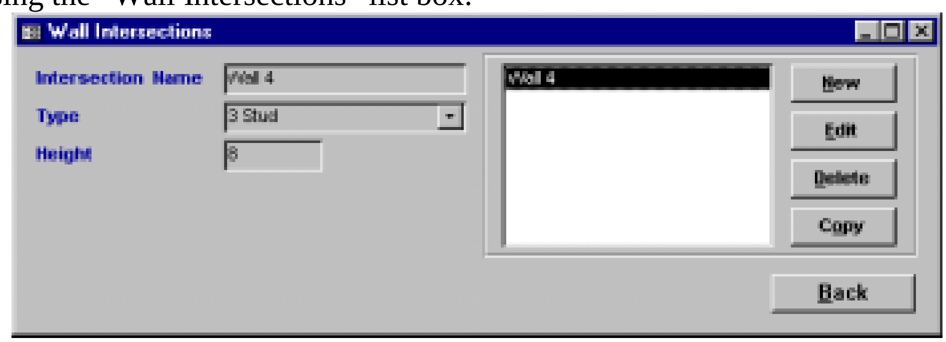


Figure I - 9: Wall Intersections Form

Few details are needed to describe a wall intersection:

Name Enter a name for the wall intersection.

Type Select the type of intersection:
3 Stud, 2 Stud, 1 Stud w/ blocking, 1 Stud w/ clips

Length Enter the length of the intersection.

Floor Form

The ***Floor*** form (Figure I - 10) allows the surveyor to enter detailed information about floor framing for each site. The information contained on the ***Floor*** form describes a floor element (a grouping of similar floor joists). A "Floor" list box allows the user to navigate through and edit floor elements.

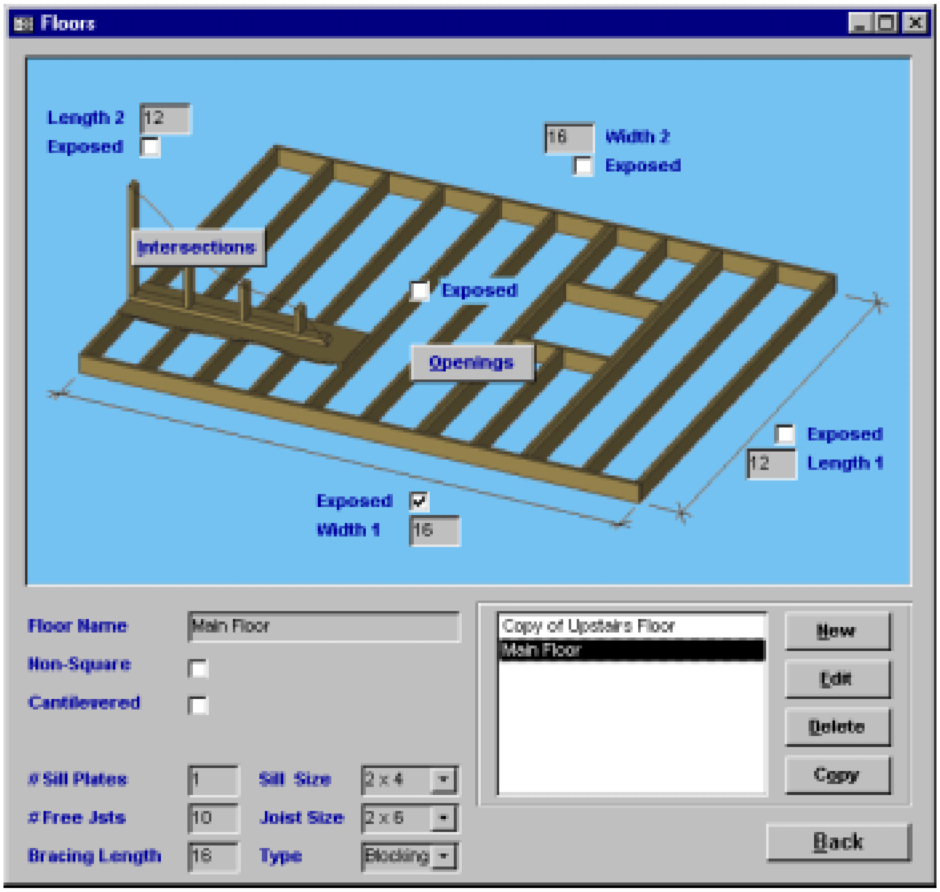


Figure I - 10: Floor Form

Like ceiling elements and wall elements, floor elements can be 3- or 4-sided. Different information is required to describe a floor element:

Name Enter a name for the floor element.

Non-square Check this box if the floor element is not rectangular.

Cantilevered Check this box if the floor element is cantilevered past the edge of the element that supports it.

Length Enter the length of the wall element. The length is measured parallel to the direction of the joists.

Width	Enter the width of the floor element. The width is measured perpendicular to the direction of the joists.
# Sill Plates	Enter the number of sill plates if the floor is supported by a foundation wall.
Sill Size	Select the size of the sill plate used: *2 x 4, 2 x 6, 2 x 8*
# Free Joists	Enter the number of free joists in the ceiling element. Free joists are joists that are NOT ring joists or part of the framing around an opening.
Joist Size	Select the size of the joists used: *2 x 6, 2 x 8, 2 x 10, 2 x 12, 12 Wood-I, 14 Wood-I, 16 Wood-I*
Bracing Length	Enter the total length of the bracing in the floor element. If there is more than one row of bracing, enter the sum of the lengths of the individual rows.
Type	Select the type of bracing used: *Blocking, Cross Bracing, Let-In, Diagonal Bracing, Strapping*

The database is updated by pressing the ***Save*** button. The surveyor can make corrections to the information in a floor element by selecting it from the "Floor" list box and pressing the ***Edit*** button. If necessary, the surveyor can remove a floor element from the database by selecting it from the "Floor" list box and pressing the ***Delete*** button.
The surveyor must also enter details about the floor openings and intersections. This is done in the forms accessed by the ***Openings*** and ***Intersections*** buttons.

Floor Openings Form

The ***Floor Openings*** (Figure I - 11) form is used to describe the framing around openings such as crawlspace accesses. A "Floor Openings" list box is used to manage floor opening elements.

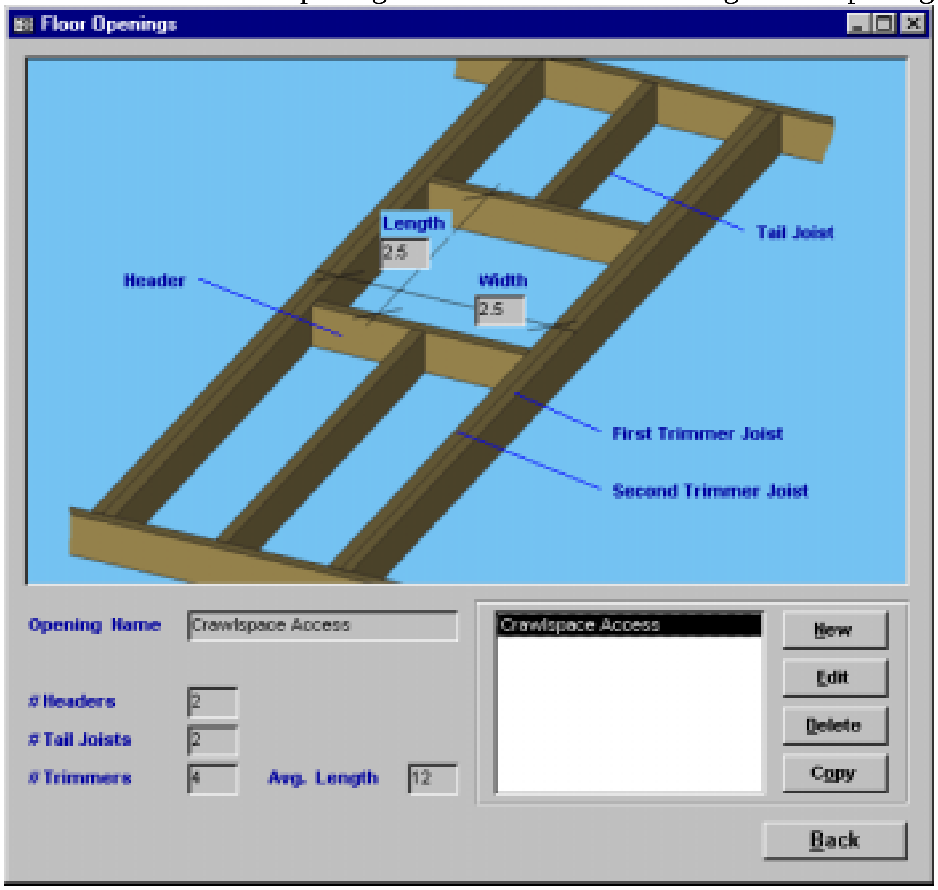


Figure I - 11: Floor Openings Form

Several details are necessary to describe each floor opening:

Name	Enter a name for the floor opening.
Length	Enter the length of the rough floor opening.
Width	Enter the width of the rough floor opening.
# Headers	Enter the total number of headers included in the floor opening. Count all headers on both ends of the opening.
# Tail Joists	Enter the total number of tail joists included in the floor opening. Count all tail joists on both ends of the opening.

 # Trimmers Enter the total number of trimmer joists included in the floor opening. Count all trimmer joists on both sides of the opening.

Avg. Length Enter the average length of the trimmers.

Floor Intersections Form

The ***Floor Intersections*** (Figure I - 12) form is used to describe the framing at intersections between the ceiling elements and interior walls. The surveyor can manage the ceiling intersection elements using the "Ceiling Intersections" list box.

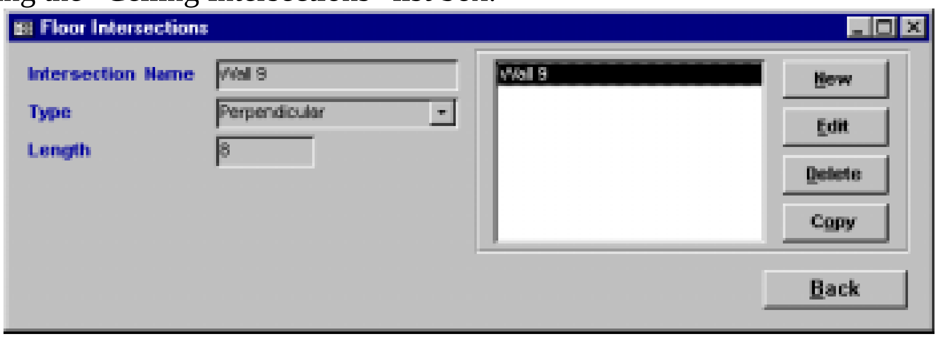


Figure I - 12: Floor Intersections Form

Few details are needed to describe a floor intersection:

Name Enter a name for the floor intersection.

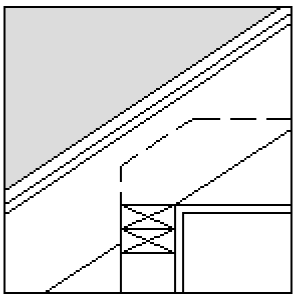
Type Select the type of intersection:
Parallel (i.e., in the direction of the joists), Perpendicular

Length Enter the length of the intersection.

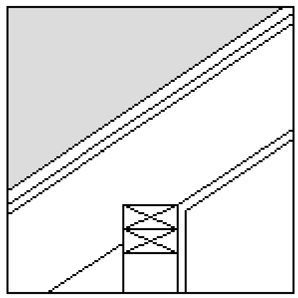
Typical Framing Details

Figure I - 13 illustrates the choices available for the Framed Roof (Section 0), Corners (Section 0), Ceiling Intersections (Section 0) and Wall Intersections (Section 0) list boxes.

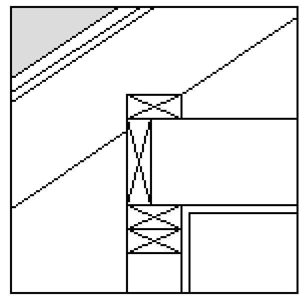
Framed Roofs @ Eave



Double Top Plate

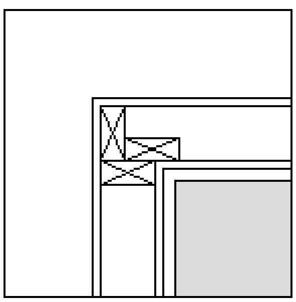


Vaulted

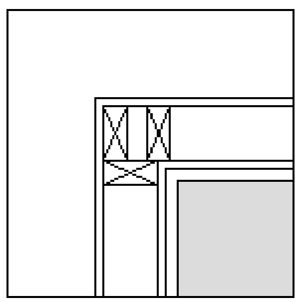


Rafter Plate

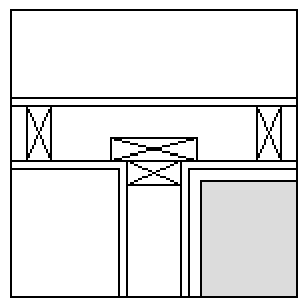
Inside Corners



3-Stud A

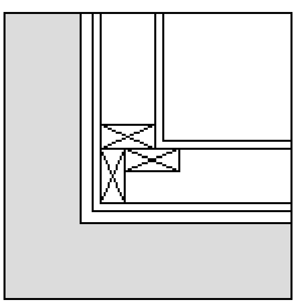


3-Stud B

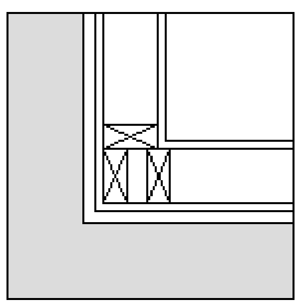


2-Stud

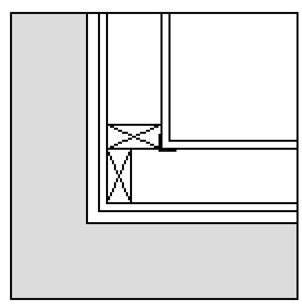
Outside Corners



3-Stud A

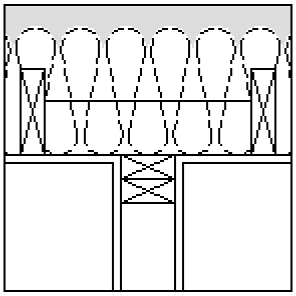


3-Stud B

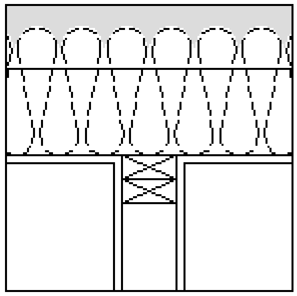


2-Stud w/ Clips

Ceiling/Wall Intersections

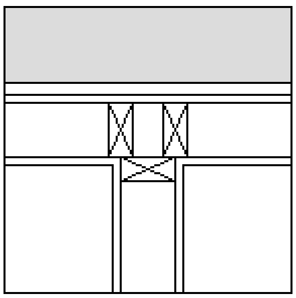


Parallel

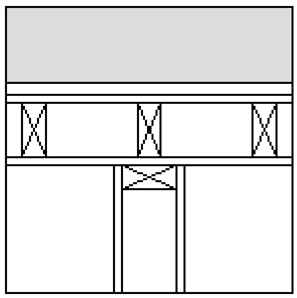


Perpendicular

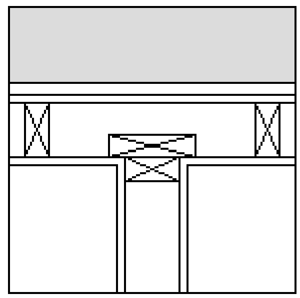
Wall/Wall Intersections



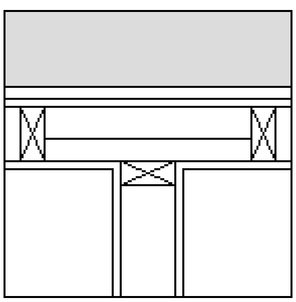
3-Stud



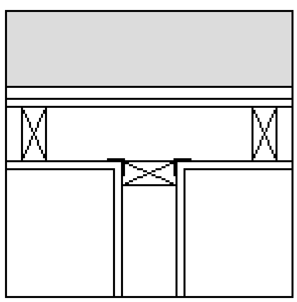
2-Stud A



2-Stud B



1-Stud w/ Blocking



1-Stud w/ Clips

Figure I - 13: Typical Framing Details

Appendix II – Audit Results for Individual Dwellings

Summary of Data - Detached Dwellings

						Framing Factors -- GROSS				Framing Factors -- NET				Ratios					
Code	Zone	Basement	House	Notes	Floor Area	Celing F.F.	Wall F.F.	Floor F.F.	Overall F.F.	Celing F.F.	Wall F.F.	Floor F.F.	Overall F.F.	Window to Wall Area	Door to Wall Area	Corner Hght to Wall Area	Exp Perim to Wall Area	Ceiling Opening to Ceiling	Floor Opening to Floor Area
D5	3	slab	one story	0	2517	7.2	21.3	0.0	12.0	7.2	27.5	0.0	14.1	14.7	7.9	0.4	0.00	0.0	0.0
D6	3	slab	one story	0	2433	7.4	24.5	0.0	10.6	7.5	30.0	0.0	11.6	13.7	4.8	0.4	0.00	0.2	0.0
D7	3	slab	one story	0	1596	8.6	21.5	0.0	11.6	8.6	25.9	0.0	12.6	9.9	7.3	0.4	0.00	0.4	0.0
D8	3	slab	one story	0	1659	6.5	19.5	0.0	9.3	6.5	23.2	0.0	10.1	10.0	6.3	0.4	0.00	0.3	0.0
D13	3	slab	one story	0	2418	10.6	20.0	0.0	12.9	10.6	26.1	0.0	14.4	9.8	13.6	0.6	0.00	0.0	0.0
D16	3	slab	one story	0	1872	7.1	20.6	0.0	10.8	7.1	24.4	0.0	11.8	11.1	4.7	0.8	0.00	0.3	0.0
D17	3	slab	one story	0	1973	6.7	19.9	0.0	10.6	6.7	24.2	0.0	11.9	10.1	7.8	0.8	0.00	0.0	0.0
D18	3	slab	one story	0	2251	6.5	24.1	0.0	11.3	6.5	29.2	0.0	12.7	13.7	3.8	0.6	0.00	0.2	0.0
D19	3	slab	two story	0	2873	5.7	25.6	0.0	11.7	5.7	30.3	0.0	13.1	12.8	2.9	0.6	0.00	0.0	0.0
D20	3	slab	one story	0	1684	5.4	25.4	0.0	13.6	5.4	32.5	0.0	16.5	16.1	5.7	0.4	0.00	0.0	0.0
D21	3	slab	two story	0	2519	7.4	23.5	0.0	14.1	7.5	30.1	0.0	16.9	18.5	3.2	0.4	0.53	0.6	0.0
D1	4	slab	two story	0	2556	7.7	20.7	0.0	12.3	7.7	25.6	0.0	14.0	13.9	5.4	0.4	0.64	0.5	0.0
D2	4	slab	one story	0	1981	7.5	22.5	0.0	10.2	7.5	28.0	0.0	11.3	13.3	6.5	0.6	0.00	0.3	0.0
D3	4	slab	one story	0	2357	6.7	21.4	0.0	9.9	6.7	26.4	0.0	11.0	15.2	3.9	0.4	0.00	0.4	0.0
D4	4	slab	two story	0	2984	6.6	22.2	0.0	11.8	6.6	27.7	0.0	13.7	16.0	3.9	0.8	0.15	0.6	0.0
D9	4	slab	two story	0	1315	7.0	22.3	0.0	16.2	7.0	25.7	0.0	18.3	9.4	4.1	0.8	0.62	0.6	0.0
D10	4	slab	two story	0	1467	6.6	22.2	0.0	13.3	6.6	25.7	0.0	14.8	9.4	4.0	0.6	0.51	0.5	0.0
D11	4	slab	two story	0	2326	7.0	20.6	0.0	10.7	7.0	23.9	0.0	11.7	10.9	2.8	0.4	0.21	0.4	0.0
D12	4	slab	two story	0	1983	5.4	19.6	0.0	10.7	5.4	22.7	0.0	11.9	8.9	5.0	0.4	0.17	0.0	0.0
D14	4	slab	two story	0	2043	6.2	22.3	0.0	11.1	6.2	26.1	0.0	12.3	10.9	3.6	0.5	0.40	0.5	0.0
D15	4	slab	two story	0	1536	7.0	21.5	0.0	13.9	7.0	24.9	0.0	15.5	10.4	3.0	0.6	0.33	0.0	0.0
D22	4	slab	one story	0	1271	6.5	17.0	0.0	9.8	6.5	19.3	0.0	10.5	6.4	5.5	0.4	0.00	0.4	0.0
D23	4	slab	one story	0	1483	7.1	19.0	0.0	9.5	7.1	22.3	0.0	10.2	6.7	8.1	0.5	0.00	0.3	0.0
D24	4	slab	one story	0	1830	7.1	20.3	0.0	9.6	7.1	23.0	0.0	10.2	6.9	4.7	0.4	0.00	0.3	0.0
D25	4	slab	one story	0	2068	6.9	20.8	0.0	9.6	6.9	24.4	0.0	10.3	7.7	6.8	0.4	0.00	0.2	0.0
D26	4	slab	one story	0	1357	6.7	18.3	0.0	8.8	6.7	21.0	0.0	9.3	8.0	5.0	0.3	0.00	0.3	0.0
D27	4	slab	one story	0	1659	5.6	18.7	0.0	10.0	5.6	21.1	0.0	10.8	6.8	4.8	0.4	0.44	0.0	0.0
D28	4	slab	two story	0	2829	7.3	22.8	0.0	12.9	7.3	27.3	0.0	14.6	13.2	3.2	0.4	0.52	0.3	0.0
D29	4	slab	two story	0	2548	6.7	24.1	0.0	14.0	6.7	31.8	0.0	17.2	21.5	2.6	0.4	0.15	0.3	0.0
D30	4	slab	two story	0	2626	6.3	25.0	0.0	14.3	6.3	31.7	0.0	17.2	18.2	3.0	0.6	0.24	0.0	0.0
			Averages:		**Overall**	**6.9**	**21.6**	**0.0**	**11.6**	**6.9**	**26.1**	**0.0**	**13.0**	**11.8**	**5.1**	**0.5**	**0.38**	**0.4**	**0.0**
					Zone 3	**7.2**	**22.3**	**0.0**	**11.7**	**7.2**	**27.6**	**0.0**	**13.3**	**12.8**	**6.2**	**0.5**	**0.53**	**0.3**	**0.0**
					Zone 4	**6.7**	**21.1**	**0.0**	**11.5**	**6.7**	**25.2**	**0.0**	**12.9**	**11.2**	**4.5**	**0.5**	**0.36**	**0.4**	**0.0**
			Standard Deviations:		**Overall**	**0.9**	**2.1**	**0.0**	**1.8**	**0.9**	**3.3**	**0.0**	**2.5**	**3.8**	**2.2**	**0.1**	**0.2**	**0.2**	**0.0**
					Zone 3	**1.4**	**2.2**	**0.0**	**1.6**	**1.4**	**2.9**	**0.0**	**2.2**	**2.8**	**3.0**	**0.2**	**0.2**	**0.2**	**0.0**
					Zone 4	**0.5**	**2.0**	**0.0**	**2.0**	**0.5**	**3.3**	**0.0**	**2.7**	**4.1**	**1.4**	**0.1**	**0.2**	**0.2**	**0.0**

Summary of Data - Attached Dwellings

						Framing Factors -- GROSS				Framing Factors -- Net				Ratios					
Code	Zone	Basement	House	Notes	Floor Area	Ceiling F.F. (Gross)	Wall F.F. NEW	Floor F.F. Gross	Overall F.F. NEW	Ceiling F.F.	Wall F.F.	Floor F.F.	Overall F.F.	Window to Wall Area	Door to Wall Area	Corner Hght to Wall Area	Exp Perim to Wall Area	Ceiling Opening to Ceiling Area	Floor Opening to Floor Area
A8	3	slab	one story	0	1642	6.9	17.6	0.0	9.7	6.9	22.2	0.0	11.0	11.8	9.1	0.6	0.00	0.4	0.0
A9	3	slab	one story	0	1642	6.9	18.4	0.0	9.0	7.0	23.5	0.0	10.0	12.5	9.0	0.9	0.00	0.4	0.0
A1	4	slab	two story	0	1792	8.6	24.4	0.0	13.1	8.7	30.6	0.0	14.8	14.7	5.5	0.8	0.25	0.5	0.0
A2	4	slab	two story	0	2158	6.7	23.3	0.0	10.0	6.7	29.6	0.0	11.3	16.1	5.4	0.7	0.29	0.6	0.0
A3	4	slab	two story	0	1757	7.6	23.0	0.0	11.6	7.6	31.4	0.0	13.7	16.6	11.3	0.8	0.23	0.0	0.0
A4	4	slab	two story	0	1672	7.8	21.7	0.0	12.6	7.9	25.4	0.0	13.9	8.9	5.7	0.8	0.19	0.5	0.0
A5	4	slab	two story	0	1678	6.5	20.7	0.0	9.4	6.5	24.0	0.0	10.1	7.6	6.2	0.7	0.34	0.0	0.0
A6	4	slab	two story	0	1500	6.8	22.3	0.0	10.2	6.8	25.9	0.0	11.0	7.8	6.2	0.8	0.31	0.0	0.0
A7	4	slab	two story	0	1344	6.6	20.4	0.0	11.6	6.6	23.7	0.0	12.7	10.0	3.8	0.7	0.08	0.0	0.0
A10	4	slab	two story	0	1216	9.2	21.3	0.0	15.8	9.3	25.1	0.0	17.9	12.3	2.8	0.6	0.21	0.8	0.0
A11	4	slab	two story	garage under	1594	6.6	22.0	0.0	14.8	6.6	27.7	0.0	17.9	6.8	14.7	1.3	0.16	0.6	0.0
A12	4	slab	two story	garage under	1259	7.6	21.5	0.0	13.5	7.7	25.7	0.0	15.4	10.3	6.2	1.6	0.45	0.7	0.0
A13	4	slab	one story	0	1039	9.9	22.2	0.0	16.9	9.9	26.3	0.0	19.3	11.2	4.4	0.4	0.23	0.5	0.0
A14	4	slab	two story	0	1131	6.9	21.9	0.0	12.2	7.0	27.8	0.0	14.3	12.5	8.6	0.9	0.20	0.6	0.0
A15	4	slab	two story	0	1368	6.4	20.4	0.0	11.8	6.4	25.1	0.0	13.6	12.6	6.1	0.8	0.16	0.6	0.0
A16	4	slab	two story	0	1471	5.9	23.5	0.0	10.1	5.9	31.7	0.0	12.1	19.0	7.0	0.9	0.23	0.6	0.0
A17	4	slab	two story	0	1766	6.1	21.0	0.0	8.9	6.1	26.3	0.0	9.9	14.2	5.8	1.1	0.16	0.5	0.0
A18	4	slab	two story	0	1141	9.3	22.6	0.0	19.0	9.4	28.0	0.0	23.0	12.8	6.6	0.8	0.38	0.6	0.0
			Averages:		**Overall**	**7.3**	**21.6**	**0.0**	**12.2**	**7.4**	**26.7**	**0.0**	**14.0**	**12.0**	**6.9**	**0.8**	**0.24**	**0.6**	**0.0**
					Zone 3	**6.9**	**18.0**	**0.0**	**9.4**	**6.9**	**22.8**	**0.0**	**10.5**	**12.1**	**9.0**	**0.7**	**0.00**	**0.4**	**0.0**
					Zone 4	**7.4**	**22.0**	**0.0**	**12.6**	**7.4**	**27.1**	**0.0**	**14.4**	**12.0**	**6.6**	**0.8**	**0.24**	**0.6**	**0.0**
			Standard Deviations:		**Overall**	**1.1**	**1.3**	**0.0**	**2.8**	**1.1**	**2.4**	**0.0**	**3.5**	**3.2**	**2.7**	**0.3**	**0.1**	**0.3**	**0.0**
					Zone 3	**0.7**	**0.2**	**0.0**	**1.1**	**0.7**	**1.3**	**0.0**	**1.7**	**0.4**	**4.2**	**0.1**	**0.0**	**0.4**	**0.0**
					Zone 4	**1.2**	**1.2**	**0.0**	**2.9**	**1.2**	**2.1**	**0.0**	**3.6**	**3.1**	**2.6**	**0.3**	**0.1**	**0.3**	**0.0**

Summary of Data - Multi-family Dwellings

						Framing Factors -- GROSS				Framing Factors -- Net				Ratios					
Code	Zone	Basement	House	Notes	Floor Area/Unit	Celing F.F. (Gross)	Wall F.F. (Gross)	Floor F.F. Gross	Overall F.F. (Gross)	Celing F.F.	Wall F.F.	Floor F.F.	Overall F.F.	Window to Wall Area	Door to Wall Area	Corner Hght to Wall Area	Exp Perim to Wall Area	Ceiling Opening to Ceiling Area	Floor Opening to Floor Area
M2	3	slab	2 story	2/8 units	1119	8.3	21.0	0.0	16.9	4.2	25.4	0.0	18.6	10.7	6.3	0.7	0.92	0.4	0.0
M3	3	slab	3 story	5/20 units	4861	8.1	20.8	0.0	16.7	8.2	24.8	0.0	19.5	10.9	5.3	0.7	0.66	0.4	0.0
M7	3	slab	3 story	5/20 units	693	3.0	21.6	0.0	17.7	7.2	27.7	0.0	23.4	9.9	12.1	1.0	0.38	0.1	0.0
M8	3	slab	2 story	4/16 units	961	7.4	19.6	0.0	15.2	7.4	23.7	0.0	17.9	8.7	8.5	1.0	0.88	0.0	0.0
M1	4	slab	2 story	4/16 units	938	6.7	20.3	0.0	15.4	6.7	23.9	0.0	17.7	4.2	10.4	0.6	0.57	0.0	0.0
M4	4	slab	2 story	4/16 units	970	5.9	19.8	0.0	14.9	5.9	26.1	0.0	18.9	15.9	8.1	0.8	0.50	0.5	0.0
M5	4	slab	2 story	4/8 units	1156	6.3	20.4	0.0	14.3	8.1	28.6	0.0	19.6	21.2	7.0	0.9	0.21	0.6	0.0
M6	4	slab	3 story	6/24 units	1140	2.3	22.9	0.0	18.8	6.8	29.9	0.0	25.3	13.4	9.8	1.2	0.60	0.0	0.0
M9	4	slab	3 story	5/32 units	904	8.0	21.8	0.0	16.8	3.6	28.7	0.0	19.6	9.0	14.6	1.0	0.51	0.0	0.0
M10	4	slab	3 story	4/7 units	956	6.9	23.0	0.0	20.5	6.9	28.6	0.0	25.3	10.8	9.8	0.9	0.64	0.5	0.0
M11	4	slab	3 story	6/24 units	1052	12.7	22.0	0.0	20.0	12.7	26.5	0.0	23.5	4.7	12.1	0.9	0.76	0.0	0.0
M12	4	slab	3 story	6/24 units	798	7.2	23.5	0.0	19.7	2.4	32.4	0.0	25.4	10.0	17.4	1.1	0.48	0.0	0.0
			Averages:		**Overall**	**6.9**	**21.4**	**0.0**	**17.2**	**6.7**	**27.2**	**0.0**	**21.2**	**10.8**	**10.1**	**0.9**	**0.59**	**0.4**	**0.0**
					Zone 3	**6.7**	**20.7**	**0.0**	**16.6**	**6.7**	**25.4**	**0.0**	**19.8**	**10.0**	**8.1**	**0.9**	**0.71**	**0.3**	**0.0**
					Zone 4	**7.0**	**21.7**	**0.0**	**17.5**	**6.6**	**28.1**	**0.0**	**21.9**	**11.1**	**11.1**	**0.9**	**0.54**	**0.5**	**0.0**
			Standard Deviations:		**Overall**	**2.3**	**1.3**	**0.0**	**2.1**	**2.5**	**2.5**	**0.0**	**2.9**	**4.6**	**2.9**	**0.2**	**0.2**	**0.3**	**0.0**
					Zone 3	**0.6**	**0.4**	**0.0**	**0.5**	**0.9**	**2.3**	**0.0**	**0.9**	**7.5**	**1.4**	**0.2**	**0.3**	**0.3**	**0.0**
					Zone 4	**2.8**	**0.9**	**0.0**	**1.6**	**3.0**	**2.2**	**0.0**	**2.4**	**2.5**	**3.0**	**0.1**	**0.1**	**0.2**	**0.0**

Floor Area Distribution for Survey Site Selection Criteria

Table 3 and Table 4 illustrate the distribution of houses constructed in the Western Census region in 1999 (based on floor area). The data used for these figures were adapted from the US Census Bureau reports on the "Characteristics of New Housing". This data can be easily accessed at http://www.census.gov/const/www/charindex.html. Data is currently available for the years 1994 through 2000. For convenience, the data for 1999 has been reproduced in the following table:

Table II - 1: U.S. Census Bureau Data for Distribution of Dwellings by Floor Area – Western Census Region

Single-Family Dwellings			Multi-Family Dwellings		
	Number of Units	Percent Distribution		Number of Units	Percent Distribution
Under 1,200 ft²	17,000	5	Under 600 ft²	1,000	0
1,200 to 1,599	62,000	20	600 to 799	11,000	4
1,600 to 1,999	74,000	24	800 to 999	27,000	9
2,000 to 2,399	53,000	17	1,000 to 1,199	23,000	7
2,400 to 2,999	52,000	17	1,200 plus	22,000	7
3,000 plus	51,000	16			
Total	310,000	100	Total	85,000	27

Geographic Distribution for Survey Site Selection Criteria

Table 5 and Table 6Table II - 2 illustrate the geographic distribution of housing starts in the State of California in 1999 (based on permits issued). The data sources for these figures are the U.S. Bureau of Census and the Real Estate Center at Texas A&M University. Table II - 2 shows the housing starts for California Metropolitan Statistical Areas (MSAs). Table II - 3 summarizes the data in Table II - 2 on the basis of zone and dwelling type (i.e. single- or multi-family). The distribution shown in Table II -3 was used as the basis for establishing the geographic distribution of survey sites shown in Table II - 4.

Table II - 2: Summary of Housing Start Data for Selected MSAs in the State of California

Metropolitan Statistical Area	Counties Included	Map ID	Location latitude	Location longitude	seismic zone	Housing Starts (1000s) single family	Housing Starts (1000s) multi-family	Dot size on Map	
Bakersfield	Kern	1	35.42	119.05	4	2.89	0.23	4.5	
Fresno	Fresno, Madera	2	36.77	119.72	3	3.09	0.49	4.8	
Los Angeles	Los Angeles	3	33.93	118.40	4	7.83	6.23	9.5	
Oakland	Alameda,Contra Costa	4	37.82	122.32	4	8.85	1.96	8.3	
Orange County	Orange	5	33.00	117.00	4	7.68	4.56	8.9	
Riverside	Riverside, San Bernardino	6	33.90	117.25	4	19.02	1.9	11.6	
Sacramento	Sacramento, Placer, El Dorado	7	38.52	121.50	3	10.28	2.74	9.2	
Salinas	Monterey	8	36.67	121.60	4	1.48	0.57	3.6	
San Diego	San Diego	9	32.73	117.17	4	10.07	6.23	10.2	
San Francisco	San Francisco, San Mateo, Marin	10	37.62	122.38	4	1.66	2.73	5.3	
San Jose	Santa Clara	11	37.37	121.93	4	3.32	3.56	6.7	
Santa Barbara	Santa Barbara	12	34.43	119.83	4	0.62	0.19	2.3	
Santa Rosa	Sonoma	13	38.52	122.82	4	2.35	0.69	4.4	
Stockton	San Joaquin	14	37.90	121.25	3	4.19	0.01	5.2	
Vallejo	Solano, Napa	15	38.00	122.00	4	2.08	0.64	4.2	
Ventura	Ventura	16	34.00	119.00	4	3.64	0.78	5.3	
Visalia	Tulare	17	36.33	119.30	3	1.54	0.1	3.3	
						90.59	33.61	800	Mag
						73%	27%	0.5	Exp

Table II - 3: Percent Distribution of Starts for CA

		single family	multi-family	%
Zone Total	4	71.49	30.27	82%
	3	19.1	3.34	18%
Zone %	4	58%	24%	
	3	15%	3%	

Table II - 4: Distribution of Starts for Site Selection

Distribution of Sites for California Survey			
Total Sites	60	Zone 3	Zone 4
	Detached	8	22
	Attached	6	12
	Multi	4	8
		18	42

Floor Area Distribution of the Sites Surveyed

Upon initially receiving the results from the survey, one of the reviewers noted that none of the floor areas of the detached dwellings used in the California study were over 3000 square feet. The reviewer suggested that there has been a trend to larger dwellings and asked how the distribution of the floor areas compared to the published statistics.

In response, a spreadsheet (Figure II - 1) was prepared to compare the distribution of the floor areas from the California survey to the statistics for the Western census region (data from the US Census Bureau). The results show that the survey data is lacking in dwellings over 3000 sq. ft., but makes up for it in the 2400 to 2999 sq. ft. range. Furthermore, four of the dwellings are over 2800 sq. ft. in floor area, so it is likely that the data is representative of the general housing stock in the state of California.

California Detached Houses Floor Area	
1271	b
1315	b
1357	b
1467	b
1483	b
1536	b
1595	b
1659	c
1684	c
1830	c
1859	c
1872	c
1973	c
1981	c
1983	c
2043	d
2068	d
2251	d
2326	d
2357	d
2418	e
2433	e
2517	e
2519	e
2548	e
2555	e
2825	e
2829	e
2873	e
2984	e

Categories	Code	Count	CA Sample	US Census Bureau Western Census Data
under 1200	a	0	0%	8%
1200 to 1599	b	7	23%	21%
1600 to 1999	c	8	27%	22%
2000 to 2399	d	5	17%	17%
2400 to 2999	e	10	33%	16%
3000 plus	f	0	0%	16%
		30	100%	100%

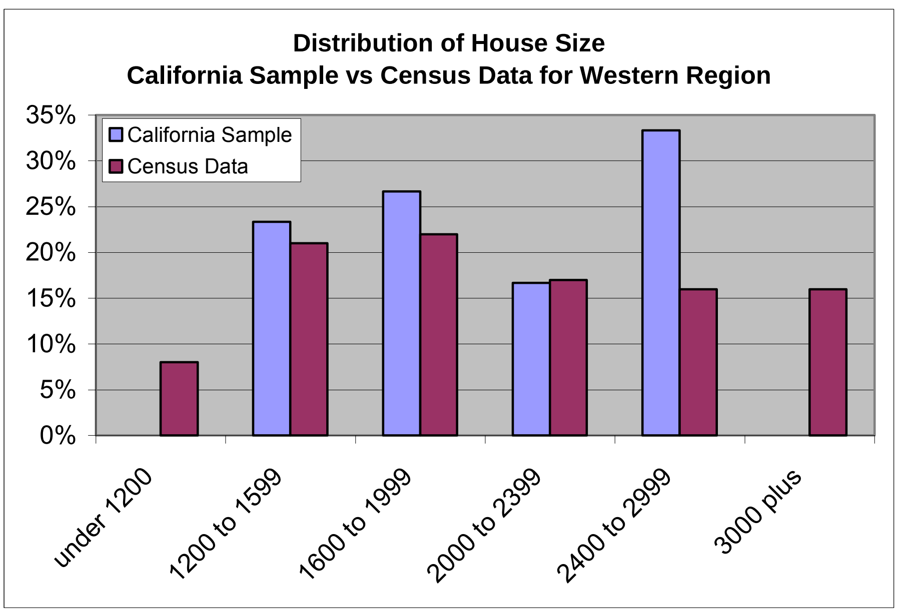


Figure II - 1: California Survey Floor Areas vs. US Census Bureau Western Region Floor Areas

Statistical Calculations

The means, standard deviations, confidence intervals and correlation coefficients quoted throughout the report were calculated using the statistical functions built into Microsoft Excel 2000. The tables used to calculate these values follow.

Mean $= \bar{x} = \frac{\sum_i x}{n}$ where n = number of samples x_i = parameter value for sample i	Correlation Coefficient $= \rho_{x,y} = \frac{\mathrm{Cov}(X,Y)}{\sigma_x \cdot \sigma_y}$ where $-1 \le \rho_{x,y} \le 1$ $\mathrm{Cov}(X,Y) = \frac{1}{n}\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y)$ n = number of samples x_i = parameter value for sample i μ_x = mean of x values y_i = parameter value for sample i μ_y = mean of y values
Confidence Interval $= \bar{x} \pm t\frac{s}{\sqrt{n}}$ where $t = 1.96$ for 0.05 alpha (95% confidence level) s = standard deviation of the sample n = number of samples	
Standard Deviation $= s = \sqrt{\frac{n\sum x^2 - \left(\sum x\right)^2}{n(n-1)}}$ where n = number of samples x_i = parameter value for sample i	

Calculated Statistics – Detached Dwellings

Detached Housing								Framing Factors -- NET				Ratios				
Code	City	Zone	House Type	Bsmnt	Stories	Surveyor	Floor Area	Celing F.F.	Wall F.F.	Floor F.F.	Overall F.F.	Corner Hght to Wall Area	Exp Perim to Wall Area	Ceiling Opening to Ceiling	Floor Opening to Floor Area	Win+Dr Wall Ratios
D5	Redding	3	Single Detached	slab	1	Rick Chitwood	2517	7.2	27.5	0.0	14.1	0.4	0.0	0.0	0.0	22.6
D6	Redding	3	Single Detached	slab	1	Rick Chitwood	2430	7.5	30.0	0.0	11.6	0.4	0.0	0.2	0.0	18.5
D7	Chico	3	Single Detached	slab	1	Rick Chitwood	1595	8.6	25.9	0.0	12.6	0.4	0.0	0.4	0.0	17.1
D8	Chico	3	Single Detached	slab	1	Rick Chitwood	1659	6.5	23.2	0.0	10.1	0.4	0.0	0.3	0.0	16.3
D13	Redding	3	Single Detached	slab	1	Rick Chitwood	2418	10.6	26.1	0.0	14.4	0.6	0.0	0.0	0.0	23.4
D16	Sacramento	3	Single Detached	slab	1	Rick Chitwood	1872	7.1	24.4	0.0	11.8	0.8	0.0	0.3	0.0	15.7
D17	Sacramento	3	Single Detached	slab	1	Rick Chitwood	1973	6.7	24.2	0.0	11.9	0.8	0.0	0.0	0.0	17.9
D18	Sacramento	3	Single Detached	slab	1	Rick Chitwood	2251	6.5	29.2	0.0	12.7	0.6	0.0	0.2	0.0	17.5
D19	Sacramento	3	Single Detached	slab	2	Rick Chitwood	2873	5.7	30.3	0.0	13.1	0.6	0.0	0.0	0.0	15.7
D20	Rocklin	3	Single Detached	slab	1	Rick Chitwood	1684	5.4	32.5	0.0	16.5	0.4	0.0	0.0	0.0	21.8
D21	Rocklin	3	Single Detached	slab	2	Rick Chitwood	2519	7.5	30.1	0.0	16.9	0.4	6.4	0.6	0.0	21.7
D1	Brentwood	4	Single Detached	slab	2	Chitwood & Schumacher	2555	7.7	25.6	0.0	14.0	0.4	7.7	0.5	0.0	19.4
D2	Brentwood	4	Single Detached	slab	1	Chitwood & Schumacher	1981	7.5	28.0	0.0	11.3	0.6	0.0	0.3	0.0	19.8
D3	Doublin	4	Single Detached	slab	1	Chitwood & Schumacher	2357	6.7	26.4	0.0	11.0	0.4	0.0	0.4	0.0	19.1
D4	Doublin	4	Single Detached	slab	2	Chitwood & Schumacher	2984	6.6	27.7	0.0	13.7	0.8	1.7	0.6	0.0	19.9
D9	Davis	4	Single Detached	slab	2	Rick Chitwood	1315	7.0	25.7	0.0	18.3	0.8	7.4	0.6	0.0	13.5
D10	Davis	4	Single Detached	slab	2	Rick Chitwood	1467	6.6	25.7	0.0	14.8	0.6	6.1	0.5	0.0	13.4
D11	Vallejo	4	Single Detached	slab	2	Rick Chitwood	2326	7.0	23.9	0.0	11.7	0.4	2.5	0.4	0.0	13.8
D12	Vallejo	4	Single Detached	slab	2	Rick Chitwood	1983	5.4	22.7	0.0	11.9	0.4	2.1	0.0	0.0	13.9
D14	Vacaville	4	Single Detached	slab	2	Rick Chitwood	2043	6.2	26.1	0.0	12.3	0.5	4.6	0.5	0.0	14.5
D15	Vacaville	4	Single Detached	slab	2	Rick Chitwood	1536	7.0	24.9	0.0	15.5	0.6	4.0	0.0	0.0	13.4
D22	Bakersfield	4	Single Detached	slab	1	Rick Chitwood	1271	6.5	19.3	0.0	10.5	0.4	0.0	0.4	0.0	11.9
D23	Bakersfield	4	Single Detached	slab	1	Rick Chitwood	1483	7.1	22.3	0.0	10.2	0.5	0.0	0.3	0.0	14.7
D24	Bakersfield	4	Single Detached	slab	1	Rick Chitwood	1830	7.1	23.0	0.0	10.2	0.4	0.0	0.3	0.0	11.6
D25	Bakersfield	4	Single Detached	slab	1	Rick Chitwood	2068	6.9	24.4	0.0	10.3	0.4	0.0	0.2	0.0	14.5
D26	Bakersfield	4	Single Detached	slab	1	Rick Chitwood	1357	6.7	21.0	0.0	9.3	0.3	0.0	0.3	0.0	13.0
D27	Bakersfield	4	Single Detached	slab	1	Rick Chitwood	1869	5.6	21.1	0.0	10.8	0.4	5.3	0.0	0.0	11.5
D28	Sime Valley	4	Single Detached	slab	2	Rick Chitwood	2829	7.3	27.3	0.0	14.6	0.4	6.2	0.3	0.0	16.4
D29	Fairfield	4	Single Detached	slab	2	Rick Chitwood	2548	6.7	31.8	0.0	17.2	0.4	1.8	0.3	0.0	24.1
D30	Fairfield	4	Single Detached	slab	2	Rick Chitwood	2825	6.3	31.7	0.0	17.2	0.6	2.9	0.0	0.0	21.2
						Averages:	**Overall**	**6.9**	**26.1**	**0.0**	**13.0**	**0.5**	**4.5**	**0.4**	**0.0**	
							Zone 3	**7.2**	**27.6**	**0.0**	**13.3**	**0.5**	**6.4**	**0.3**	**0.0**	
							Zone 4	**6.7**	**25.2**	**0.0**	**12.9**	**0.5**	**4.4**	**0.4**	**0.0**	
						Standard Deviations:	**Overall**	**0.9**	**3.3**	**0.0**	**2.5**	**0.1**	**2.8**	**0.2**	**0.0**	
							Zone 3	**1.4**	**2.9**	**0.0**	**2.2**	**0.2**	**2.9**	**0.2**	**0.0**	
							Zone 4	**0.5**	**3.3**	**0.0**	**2.7**	**0.1**	**2.5**	**0.2**	**0.0**	
						Confidence	**5%**	**0.3**	**1.2**		**0.9**					
	Correlations to Net Wall Framing Factor:				**0.295225**		**0.61252809**					**0.09289257**	**0.04018628**	**-0.1084396**		**0.74974572**

Calculated Statistics – Attached Dwellings

Attached Housing								Framing Factors -- Net				Ratios				
Code	City	Zone	House Type	Bsmnt	Stories	Surveyor	Floor Area	Ceiling F.F.	Wall F.F.	Floor F.F.	Overall F.F.	Corner Hght to Wall Area	Exp Perim to Wall Area	Ceiling Opening to Ceiling Area	Floor Opening to Floor Area	
A8	Roseville	3	Single Attached	slab	1	Rick Chitwood	1642	6.9	22.2	0.0	11.0	0.6	0.0	0.4	0.0	20.9
A9	Roseville	3	Single Attached	slab	1	Rick Chitwood	1684	7.0	23.5	0.0	10.0	0.9	0.0	0.4	0.0	21.4
A1	Danville	4	Single Attached	slab	2	Chitwood & Schumacher	1792	8.7	30.6	0.0	14.8	0.8	3.0	0.5	0.0	20.2
A2	Thousand Oaks	4	Single Attached	slab	2	Rick Chitwood	2158	6.7	29.6	0.0	11.3	0.7	3.5	0.6	0.0	21.5
A3	Thousand Oaks	4	Single Attached	slab	2	Rick Chitwood	1767	7.6	31.4	0.0	13.7	0.8	2.8	0.0	0.0	26.8
A4	Thousand Oaks	4	Single Attached	slab	2	Rick Chitwood	1672	7.9	25.4	0.0	13.9	0.8	2.3	0.5	0.0	14.6
A5	Simi Valley	4	Single Attached	slab	2	Rick Chitwood	1678	6.5	24.0	0.0	10.1	0.7	4.1	0.0	0.0	13.8
A6	Simi Valley	4	Single Attached	slab	2	Rick Chitwood	1500	6.8	25.9	0.0	11.0	0.8	3.7	0.0	0.0	13.9
A7	Simi Valley	4	Single Attached	slab	2	Rick Chitwood	1344	6.6	23.7	0.0	12.7	0.7	1.0	0.0	0.0	13.9
A10	San Mateo	4	Single Attached	slab	2	Rick Chitwood	1216	9.3	25.1	0.0	17.9	0.6	2.5	0.8	0.0	15.1
A11	San Mateo	4	Single Attached	slab	2	Rick Chitwood	1594	6.6	27.7	0.0	17.9	1.3	1.9	0.6	0.0	20.5
A12	San Mateo	4	Single Attached	slab	2	Rick Chitwood	1259	7.7	25.7	0.0	15.4	1.6	5.4	0.7	0.0	16.5
A13	Chula Vista	4	Single Attached	slab	1	Rick Chitwood	1039	9.9	26.3	0.0	19.3	0.4	2.7	0.5	0.0	15.6
A14	Chula Vista	4	Single Attached	slab	2	Rick Chitwood	1131	7.0	27.8	0.0	14.3	0.9	2.5	0.8	0.0	21.1
A15	Chula Vista	4	Single Attached	slab	2	Rick Chitwood	1368	6.4	25.1	0.0	13.6	0.8	1.9	0.6	0.0	18.7
A16	Chula Vista	4	Single Attached	slab	2	Rick Chitwood	1471	5.9	31.7	0.0	12.1	0.9	2.7	0.6	0.0	26.0
A17	Chula Vista	4	Single Attached	slab	2	Rick Chitwood	1766	6.1	26.3	0.0	9.9	1.1	2.0	0.5	0.0	20.0
A18	Chula Vista	4	Single Attached	slab	2	Rick Chitwood	1141	9.4	28.0	0.0	23.0	0.8	4.6	0.6	0.0	19.4
						Averages:	**Overall**	**7.4**	**26.7**	**0.0**	**14.0**	**0.8**	**2.9**	**0.6**	**0.0**	
							Zone 3	**6.9**	**22.8**	**0.0**	**10.5**	**0.7**	**0.0**	**0.4**	**0.0**	
							Zone 4	**7.4**	**27.1**	**0.0**	**14.4**	**0.8**	**2.9**	**0.6**	**0.0**	
						Standard Deviations:	**Overall**	**1.1**	**2.4**	**0.0**	**3.5**	**0.3**	**1.3**	**0.3**	**0.0**	
							Zone 3	**0.7**	**1.3**	**0.0**	**1.7**	**0.1**	**0.5**	**0.4**	**0.0**	
							Zone 4	**1.2**	**2.1**	**0.0**	**3.6**	**0.3**	**1.3**	**0.3**	**0.0**	
						Confidence	**5%**	**0.5**	**1.1**		**1.6**					
	Correlations to Net Wall Framing Factor:				**0.443558**		**0.21194449**					**0.0924520**	**0.39251699**	**0.15801092**		**0.6503097**

Calculated Statistics – Multi-family Dwellings

Multi-Family Housing								Framing Factors -- Net				Ratios				
Code	City	Zone	House Type	Bsmnt	Stories	Surveyor	Floor Area/Unit	Celing F.F.	Wall F.F.	Floor F.F.	Overall F.F.	Corner Hght to Wall Area	Exp Perim to Wall Area	Ceiling Opening to Ceiling Area	Floor Opening to Floor Area	
M2	Roseville	3	Multi-Family	slab	2	Rick Chitwood	1119	4.2	25.4	0.0	18.6	0.7	11.1	0.4	0.0	17.0
M3	Roseville	3	Multi-Family	slab	3	Rick Chitwood	972	8.2	24.8	0.0	19.5	0.7	8.0	0.4	0.0	16.2
M7	Rocklin	3	Multi-Family	slab	3	Rick Chitwood	690	7.2	27.7	0.0	23.4	1.0	4.5	0.1	0.0	21.9
M8	Rocklin	3	Multi-Family	slab	2	Rick Chitwood	961	7.4	23.7	0.0	17.9	1.0	10.5	0.0	0.0	17.2
M1	Fairfield	4	Multi-Family	slab	2	Rick Chitwood	938	6.7	23.9	0.0	17.7	0.6	6.9	0.0	0.0	14.6
M4	Camerillo	4	Multi-Family	slab	2	Rick Chitwood	970	5.9	26.1	0.0	18.9	0.8	6.1	0.5	0.0	24.0
M5	Santa Clarita	4	Multi-Family	slab	2	Rick Chitwood	1156	8.1	28.6	0.0	19.6	0.9	2.6	0.6	0.0	28.2
M6	Valencia	4	Multi-Family	slab	3	Rick Chitwood	1140	6.8	29.9	0.0	25.3	1.2	7.2	0.0	0.0	23.2
M9	Valencia	4	Multi-Family	slab	3	Rick Chitwood	984	3.6	28.7	0.0	19.6	1.0	6.2	0.0	0.0	23.5
M10	Santa Clarita	4	Multi-Family	slab	3	Rick Chitwood	956	6.9	28.6	0.0	25.3	0.9	7.6	0.5	0.0	20.5
M11	Chula Vista	4	Multi-Family	slab	3	Rick Chitwood	1052	12.7	26.5	0.0	23.5	0.9	9.1	0.0	0.0	16.8
M12	Valencia	4	Multi-Family	slab	3	Rick Chitwood	798	2.4	32.4	0.0	25.4	1.1	5.7	0.0	0.0	27.4
						Averages:	**Overall**	**6.7**	**27.2**	**0.0**	**21.2**	**0.9**	**7.1**	**0.4**	**0.0**	
							Zone 3	**6.7**	**25.4**	**0.0**	**19.8**	**0.9**	**8.5**	**0.3**	**0.0**	
							Zone 4	**6.6**	**28.1**	**0.0**	**21.9**	**0.9**	**6.4**	**0.5**	**0.0**	
						Standard Deviations:	**Overall**	**2.5**	**2.5**	**0.0**	**2.9**	**0.2**	**2.0**	**0.3**	**0.0**	
							Zone 3	**0.9**	**2.3**	**0.0**	**0.9**	**0.2**	**3.3**	**0.3**	**0.0**	
							Zone 4	**3.0**	**2.2**	**0.0**	**2.4**	**0.1**	**1.2**	**0.2**	**0.0**	
						Confidence	**5%**	**1.4**	**1.4**		**1.6**					
	Correlations to Net Wall Framing Factor:				**0.55951**		**-0.1288701**					**0.73192054**	**-0.5191809**	**-0.0882753**		**0.81255875**